AD NUMBER
AD083868
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FROM confidential
AUTHORITY
RARDE Reclassification List No. 36, 31 Mar 1966, per doc marking

AD NUMBER
AD083868
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TO confidential
FROM secret
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20071009022

Investigation of Accidental Explosion of 1000 lb. Bomb at R.A.F. Station Marham

D. E. Jarrett

R. 830998

Incl #

OC/AP/3-5

(6)

20759

Fort Halstead,
Kent.

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October
1955

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A.R.D.E. REPORT (S) 26/55

Investigation of Accidental Explosion of 1000 lb.

Bomb at R.A.F. station Marham

D.E. Jarrett (S.2)

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Summary

An explosion occurred at R.A.F. station Marham on 20.9.54 when a tractor was towing two bomb trolleys loaded with 1000 lb. Mark 7 bombs filled RDX/TNT.

Other bombs filled at the same period with the same materials have been examined. The behaviour of RDX/TNT on heating in a confined system and the temperature attainable by rubbing a tyre on a bomb have been studied and it is concluded that the cause of the accident was the displacement of a bomb from its cradle and subsequent heating by frictional contact with a bomb trolley tyre.

Approved for publication:

H.J. Poole, Deputy Director.

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90-105

1. References

AR 26/30
A.172292/53/1/D.Arm.Eng.
I.A./43/1/2
OB.E/881

2. Introduction

An explosion occurred at R.A.F. Marham on 20th September 1954 while a tractor towing two loaded bomb trolleys was being driven around the perimeter track. The following narrative of events is taken from the evidence given at the subsequent Court of Inquiry.

"At 12.00 hours on 20.9.54 a tractor towing two loaded bomb trolleys was being driven from the explosive area towards No.115 squadron dispersal area. The route of the tractor is shown in Fig.1. There were four bombs on the forward trolley and two in the rear position on the rear trolley. About three quarters of the way across runway 24 the tractor stopped for about 30 seconds and then carried on. About 50 yds. beyond runway 24 the driver took the bomb train on the grass for an unknown period, then returned to the perimeter track. The rear bombs were noted at this point by the Station Commander as having moved slightly but not to a dangerous position. The driver continued on the perimeter track until entering runway 20 where he stopped and got down to examine the bombs on the trolleys. He then drove very slowly across runway 20 and stopped again on the other side. At this point the bombs were observed on the rear trolley, by an aircrew member, to be off the trolley cradles. The driver started slowly toward 115 squadron dispersal when an aircraft had passed and had reached a position about one third of the distance across the perimeter track when there was an explosion (12.08 hours). Four unexploded bombs were found in the area." (photographs 7 and 8).

A.R.E. (now A.R.D.E.) was requested to give evidence at the subsequent Court of Inquiry and as a result the investigations detailed in this report were undertaken.

3. Object of Investigation

To determine the cause of the incident with special reference to the findings of the Court of Inquiry which regarded frictional heating of the bomb the most likely cause.

4. Investigation

4.1 Examination of debris

The investigation opened with a visit to the R.A.F. station Marham, during which the circumstances of the accident were considered and the fragments of bomb and trolley recovered were examined.

A relatively small number of bomb fragments were recovered. These were insufficient to provide any adequate reconstruction and only limited conclusions could be drawn. No record was available of the location of the fragments when found.

The fragments of the bombs (photographs 1 and 2) varied in size from 1 ft. in length and 6 in. in width to very small pieces. Many bore evidence of detonation, (photograph 3C) and among these were some which had originated from the nose and base of a bomb. Fragments from nose and base were found which had either been driven violently into concrete or were produced when

the bomb was in contact with concrete. Very few of the smaller fragments were marked with concrete. From their outside appearance it was possible to separate the large fragments into two classes with some indication that each class was derived from one bomb.

The general inference was that an ignition occurred somewhere along a bomb body - actually from descriptions of the crater (photographs 4 and 5) the port bomb - which built up to detonation in the direction of nose and base. This would account for the presence of large fragments with marks of ignition on the inside surface (photograph 3B). The presence of other large fragments on which the exterior paint was still intact and which showed signs of fragment attack (photograph 3A) suggested that the second bomb was initiated by the explosion of the first.

The remains of the bomb trolley were examined. The force of the explosion was directed mostly forwards, the trolley rails and main frame members being twisted outwards and slightly downwards. These rails and main frame were intact up to a point which would be beneath the centre of the bombs when resting normally (photograph 6), but the rear portions could not be identified. The right hand side of the rear axle was recovered from the crater showing signs of an explosion above it. The left hand side was not recovered. The damage is consistent with the explosion of a bomb displaced from the cradle and resting above the rear axle rather than with the explosion of a bomb in its correct position. The two positions are shown in photographs 9 and 11.

4.2 Examination of other 1000 lb. bombs

From the transit bases of the six bombs concerned D.I.Arm. established that the exploded bombs were new Mark 7, R.O.F. serial numbers 62 and 206. Both bomb bodies were manufactured by the National Steel Foundries, No.62 in July 1952 and No.206 in August 1952. Both were filled with RDX/TNT 60/40 at Glascoed, No.62 on 1st August 1952, and No.206 on 14th August 1952.

It was satisfactorily established that detonators were not present in the six bombs involved, but about this period a number of disturbing factors had been observed in the manufacturing and filling stages. Incrustations had been seen on the walls of bombs reconditioned by Metal Laundries, and sand incrstations had been seen in new bombs. Restrictions had also been made on the use of cements RDIA and RD 1270. A dark coloured RDX/TNT had also been manufactured at Bridgwater. The results of investigation into the explosion at Fulbeck also showed that cracks could be present in filled bombs.

Of these possibilities D.I.Arm. has stated that RD 1270 was not used in bombs filled after November 1951, and the use of RDIA cement was restricted as from July 1952. Moreover the examination by C.S.A.R. of bombs drawn from R.A.F. stocks has not disclosed any deleterious effects due to the presence of these cements.

National Steel Foundries manufactured only new Mark 7 bombs so that the bombs concerned in the incident could not have been affected by any reconditioning process. Sand incrustations had not been observed in National Steel Foundries stock.

The possibility of cracks existing in the bombs could not be ruled out but in view of the fragmentary nature of the evidence the existence of cracks will never be substantiated. All Mark 7 castings have been checked by sonic tests at each stage of manufacture.

The materials used in filling the bombs were traced from factory records at Glascoed, and were of Bridgwater and Bishopton origin. All materials had passed inspection by D.C.I. before use, and D.C.I. have stated that there is no question of dark coloured RDX/TNT being used for the filling.

It was considered that the only information obtainable that might prove of value would be provided by an examination of bombs filled with the same material as those involved in the incident. D.A.I.S. located six of these bombs, and four have been sectioned at Shoeburyness. The results of the examination are shown in the following tables.

Table 1

Details of bombs used in the investigation

Ref. No.	Makers Symbol	Date	Filler	Date	Filling Ref. No.	Remarks
62	NSF	7/52	Glascoed	8/52	K318,319	Exploded at Marham
106	WS	7/52	Glascoed	8/52	K319	Sectioned
126	NSF	7/52	Glascoed	8/52	K317,318	Sectioned
206	NSF	8/52	Glascoed	8/52	K336,337	Exploded at Marham
72	WS	4/52	Glascoed	8/52	K336	Sectioned
174	NSF	6/52	Glascoed	8/52	K337,338	Sectioned
67	MWG	7/52	Glascoed	8/52	K336	Used in friction trial

Table 2

Examination of sectioned bombs

General features

No. of bomb	Exterior	Condition of metal	Varnish	Sealing Composition		RD 1270	RDIA	State of filling			Exploder pellets
				Nose	Tail			TNT nose	TNT tail	Main filling	
72	Fair. Some rust	Good No deep pits	RD 1177 (blue) Thick coating	3.3/4"	1/2"	None	On adaptor and exploder threads None in contact with explosive	1" Cavity 2.1/2" x 1/4"	1/4" Good	No gap at base of exploder tube. Some cavities. Biscuit not cemented in filling	Good
106	"	"	Shellac Thick coating	3.1/2"	1/2"	"	"	1" Good	1/4" Good	" " Pieces of biscuit could be lifted out	Nose exploder stuck in container
126	"	"	Shellac Very thin Rust beginning	3.1/2"	1/2"	"	"	1" Good	1/4" Good	Two cracks 1" x 1/4" at rear. Biscuit not well cemented	Good
174	"	"	Shellac Thick coating	3.3/4"	1/2"	"	"	3/4" Cavity 1" x 3/8"	1/4" Good	Good filling	Good

After this examination the filling from the bombs was removed and samples were taken from various regions. A plan showing the regions from which the samples came is given in Fig. 2. The samples were analysed by D.C.I. Bridgwater and the results are given in the tables below.

Table 3

Examination of sectioned bombs

Analysis of H.E. filling from bomb 72

Sample Ref. (See Fig.2)	RDX%	Composition Beeswax % Visual method	Composition Beeswax % Gravimetric method	V.M. %	Acidity HNO_3%	Insoluble matter Visual method	Insoluble matter Gravimetric method Total %	Insoluble matter Gravimetric method Inorg %	Grit 60BS	Grit 36BS
Outside										
A	57.3	Satis-factory	1.1	0.12	0.017	<0.05			Nil	Nil
B	59.2	"		0.02	0.021	"			"	"
C	57.8	"		0.03	0.018	"			"	"
D	59.2	"		0.11	0.016	"			"	"
E	58.6	"		0.09	0.020	"			"	"
F	57.1	"		0.06	0.020	"			"	"
G	57.0	"		0.09	0.019	"			"	"
Y	58.2	"		0.06	0.019	"			"	"
Z	44.8	"		0.06	0.022	"			"	"
Halfway										
A	56.3	"	1.1	0.13	0.019	"			"	"
B	58.1	"		0.06	0.022	"			"	"
C	58.6	"		0.04	0.014	"			"	"
D	59.3	"		0.10	0.016	"			"	"
E	58.7	"		0.11	0.021	"			"	"
F	58.2	"		0.07	0.024	"			"	"
G	59.7	"		0.04	0.017	"			"	1Fe
Y	58.1	"	0.7	0.11	0.026	"			"	Nil
Z	61.9	"		0.03	0.017	"			"	"
Centre										
A	56.8	"	1.1	0.12	0.018	"			"	"
B	58.2	"		0.05	0.023	"			"	"
C	57.8	"		0.10	0.020	"	0.04	0.02	10Fe	8Fe
D	58.1	"		0.06	0.021	"			Nil	Nil
E	58.6	"		0.08	0.022	"			"	"
F	58.5	"		0.11	0.018	"			"	"
G	58.9	"		0.09	0.019	"	0.02	<0.01	5Fe	4Fe
Y	60.5	"		0.02	0.018	"			Nil	Nil
Z	59.3	"		0.04	0.018	"			"	"

(Fe indicates a piece of ferrous metal retained either on a 60 or 36 mesh British Standard Sieve.

V.M. indicates volatile matter.

All percentages are weight/weight of RDX/TNT except that acidity is calculated on the RDX).

Table 4

Examination of sectioned bombs

Analysis of H.E. filling from bomb 106

Sample Ref. (See Fig.2)	RDX%	Composition Beeswax % Visual method	Gravi-metric method	V.M. %	Acidity HNO_3%	Insoluble matter Visual method	Gravimetric method Total %	Inorg %	Grit 60BS	36BS
Outside										
A	56.7	Satis-factory		0.07	0.017	<0.05			Nil	Nil
B	56.1	"		0.08	0.019	"			"	"
C	57.4	"		0.10	0.018	"			"	"
D	57.8	"		0.10	0.018	"			"	"
E	57.2	"		0.12	0.020	"			"	"
F	57.4	"		0.10	0.017	"			"	"
G	56.9	"		0.12	0.018	"			"	"
Y	57.4	"	0.9	0.09	0.017	"			"	"
Z	57.2	"		0.13	0.018	"			"	"
Halfway										
C	58.5	"		0.07	0.021	"			"	"
D	59.5	"		0.11	0.018	"	0.03	<0.01	"	"
E	57.4	"		0.12	0.020	"			"	"
F	57.4	"		0.13	0.017	"			"	"
G	59.6	"		0.04	0.018	"			"	1 cinder
Centre										
A	58.3	"		0.08	0.016	"			"	Nil
B	56.1	"		0.08	0.019	"			"	"
C	59.2	"		0.10	0.017		0.12	0.05	Many Fe	11Fe
D	59.8	"		0.08	0.020	0.05	0.03	<0.01	Nil	Nil
F	58.3	"		0.06	0.015	"			"	"
G	60.3	"		0.04	0.017	"			8Fe	6Fe
Y	54.7	"	1.0	0.10	0.015	"	0.03	<0.01	Nil	Nil
Z	59.2	"		0.10	0.018	"			"	"

Table 5

Examination of sectioned bombs

Analysis of H.E. filling from bomb 126

Sample Ref. (See Fig.2)	RDX%	Composition Beeswax % Visual method	Composition Beeswax % Gravimetric method	V.M. %	Acidity HNO_3%	Insoluble matter Visual method	Insoluble matter Gravimetric method Total %	Insoluble matter Gravimetric method Inorg %	Grit 60BS	Grit 36BS
Outside										
B	57.2	Satisfactory		0.12	0.021	<0.05			Nil	Nil
C	58.4	"		0.06	0.018	"	0.04	<0.01	6Fe	"
D	60.2	"	0.8	0.07	0.020	"			Nil	"
E	56.3	"		0.06	0.020	"			"	"
F	57.8	"		0.06	0.025	"			"	"
G	58.8	"		0.08	0.023	"	0.02	<0.01	3 cinders	"
Y	57.6	"		0.04	0.020	"			Nil	"
Z	52.6	"		0.03	0.019	"			"	"
Halfway										
A	59.5	"		0.09	0.020	"			"	"
B	58.4	"		0.06	0.023	"			"	"
C	58.6	"		0.03	0.020	"			6Fe	"
D	59.4	"		0.06	0.021	"			Nil	"
E	58.3	"		0.08	0.020	"			"	"
F	57.9	"		0.12	0.026	"			"	"
G	58.0	"		0.08	0.025	"			"	"
Y	60.4	"	0.8	0.03	0.019	"			"	"
Z	59.1	"		0.03	0.019	"			"	"
Centre										
A	59.0	"		0.09	0.022	"			"	"
C	59.0	"		0.07	0.019	"			"	"
D	58.8	"		0.07	0.021	"			"	"
E	58.8	"		0.05	0.021	"			"	"
F	59.2	"		0.06	0.023	"			"	"
G	58.0	"		0.07	0.023	"			"	"
Y	59.1	"		0.02	0.019	"			"	"
Z	57.0	"	0.8	0.03	0.023	"			"	"

Table 6

Examination of sectioned bombs

Analysis of H.E. filling from bomb 174

Sample Ref. (See Fig.2)	RDX%	Composition Beeswax % Visual method	Composition Beeswax % Gravimetric method	V.M. %	Acidity HNO_3%	Insoluble matter Visual method	Insoluble matter Gravimetric method Total %	Insoluble matter Gravimetric method Inorg %	Grit 60BS	Grit 36BS
Outside										
A	57.0	Satisfactory	0.9	0.07	0.023	<0.05			Nil	Nil
B	56.4	"		0.07	0.022	"			"	"
C	55.9	"		0.12	0.020	"	0.06	<0.01	"	"
D	56.9	"		0.07	0.019	"			"	"
E	59.1	"		0.12	0.021	"			3Fe	"
F	59.4	"	1.0	0.10	0.019	"			1Al	1 cinder
G	56.4	"		0.04	0.020	"			Nil	Nil
H	57.5	"		0.09	0.021	"			"	"
Halfway										
A	58.1	"		0.03	0.022	"			"	"
B	59.4	"		0.07	0.019	"			"	"
C	57.0	"		0.08	0.022		0.21	<0.15	"	"
D	58.8	"		0.06	0.022	"			"	"
E	58.5	"		0.14	0.021	"			"	"
F	59.3	"		0.09	0.023	"			"	"
G	59.2	"		0.07	0.018	"			11Fe	"
H	57.0	"		0.04	0.017	"			Nil	"
Centre										
A	58.6	"	1.0	0.09	0.021	"			"	"
B	58.2	"		0.06	0.022	"			"	"
C	58.4	"		0.13	0.025	"	0.04	0.01	"	"
D	56.9	"		0.11	0.026	"			"	"
E	56.6	"		0.11	0.027	"	0.01	0.01	"	"
F	58.3	"	1.1	0.11	0.022	"			"	"
G	57.2	"		0.07	0.020	"			"	"
H	55.6	"		0.04	0.020	"			"	"

The figures for RDX and beeswax percentage given in the last four tables are also shown in Figs.3 - 6 superimposed on a diagram of the bomb.

The figures for RDX content are slightly low in relation to the specification for 60/40 RDX/TNT, but this arises from the fact that 3% of TNT was added to the liquid part of the filling at the time of melting to improve its flow properties. The ferrous metal particles found were in every case in the form of turnings and are adventitious impurities produced during the sectioning. The percentage of beeswax is within the specification limits of 1.0 ± 0.3%. The figures for percentage of volatile matter are all within the specification limit of 0.15%, and those for percentage of nitric acid within the limit for RDX/TNT type C.

A smaller number of samples were selected and tested for sensitivity to impact.

Table 7

Examination of sectioned bombs

Sensitivity tests

Sample	Height of fall of 5 kilo weight (cm)	No. of caps struck	No. of ignitions	Total gas (ccs)
Bomb 72				
B outside	150	10	0	0
D outside	150	10	3	8
D halfway	150	10	3	6
Z halfway	150	10	1	3
Z centre	150	10	0	0
Bomb 106				
C centre	150	10	0	0
D halfway	150	10	1	2
D centre	150	10	2	4
G halfway	150	10	8	10
G centre	150	10	9	18
Bomb 126				
A halfway	150	10	1	2
D outside	150	10	4	7
D halfway	150	10	5	10
F centre	150	10	3	4
Y halfway	150	10	6	12
Bomb 174				
B centre	150	10	2	3
C halfway	150	10	5	8
C centre	150	10	1	3
F outside	150	10	7	11
F centre	150	10	3	5

These samples show a somewhat greater sensitivity than is usual for RDX/TNT 60/40, but this is not unreasonable since they were taken after sectioning, and small ferrous particles and rust may be present.

Ignition points were also determined for these samples. They are shown in Table 8 and plotted together with the sensitivity results on diagrams of the bombs in Figs.7 - 10.

Table 8

Examination of sectioned bombs

Ignition points

Sample	Ignition Point °C.	Sample	Ignition Point °C.
Bomb 72		Bomb 126	
B outside	192	A halfway	196
D outside	192	D outside	198
D halfway	192	D halfway	196
G halfway	195	F centre	194
Z halfway	198	Y halfway	197
Z centre	194		
Bomb 106		Bomb 174	
C centre	197	B centre	198
D halfway	198	C halfway	199
D centre	196	C centre	199
G halfway	203	F outside	195
G centre	197	F centre	197
		G halfway	196

These figures are normal.

Vacuum stability tests were carried out on the RDX/TNT mixed with varnish and the TNT mixed with sealing composition.

Table 9

Examination of sectioned bombs

Vacuum stability tests

Bomb No.	Gas obtained from 5 grams of sample after 40 hours at 120°C. (cc.)	
	RDX/TNT + varnish from walls (99/1)	TNT + sealing composition (50/50)
72	0.2	2.9
106	0.5	2.9
126	0.6	2.0
174	0.4	3.8

These figures are reasonable.

This examination of the filling does not therefore support any suggestion that the fillings of the bombs which exploded were not fully serviceable.

4.3 Possibility of Frictional Heating

It will be noticed in the narrative of events that evidence was given to the Court of Inquiry that at some period during the towing the bombs had slipped from their correct position on the rear trolley. The damage caused to the trolley also suggests that the bombs were displaced at the time of explosion.

That such a displacement of bombs on a trolley is easily possible was demonstrated at Marham. With only two bombs on the cradle of the trolley slight jerking started the bombs moving backwards. (photographs 9 and 10). As the centre of gravity of the bombs moved back this tendency increased until the bombs slipped from the cradle and came to rest on the framework of the trolley (photograph 11). The bombs came to rest in one of two ways. In both cases one bomb was resting with the base on the towing hook, the nose on the back upright of the cradle, and most of the weight being taken by the frame. The other bomb would fall either outside the rear wheel (photograph 12) or on the tyre of the rear wheel (photograph 13). If it fell outside the rear wheel, the tail of the inside bomb dragged on the ground, the wheel pushed the outside bomb forward and the force exerted could break the carrier (photograph 14). If it fell on top of the rear wheel a stable condition was set up, the tyre rubbing on the bomb (photograph 15). In this position towing could proceed without noticeably affecting the ease of movement. In the trials at Marham it was found that the Mark 7 bombs normally fell in the latter manner. Converted Mark 2 bombs, owing to the remains of the welded lugs present, were more difficult to shake off and usually fell in the first manner.

It was known from exploratory trials of a previous incident carried out at No.3 M.U. Milton, that appreciable local heating could be produced by the friction of a tyre on a bomb, and it was thought possible that this might be the cause of the explosion. The same suggestion had previously been made by the American Office of Ordnance and Armament to explain an explosion of a 100 lb. G.P. bomb filled T.N.T. at the U.S. 8th Air Force station (Eye) on 16th October 1945. There, a trailer was loaded with thirty-four 100 lb. G.P. bombs, unfuzed, and towed about 850 yards until, on entering the runway, one bomb exploded. It was thought that in going out of the bomb revetment the right rear wheel of the trailer hit a bump, causing the bomb nearest to it to shift and rest against the tyre. The explosion was of a very low order, no damage being done to the trailer bed, and no other bombs on the trailer being moved. The tyre was destroyed and the rear wheel of the trailer bent. The tail exploder container assembly from the bomb was blown 100 feet across the perimeter track, and the bomb itself split open but remained in one piece. The damage is shown in photographs 16 -21.

Experiments were therefore performed to determine the effect of heat on confined RDX/TNT systems, with tests to determine whether sufficient heat could be liberated by friction of tyre on bomb to produce such an incident.

4.4 Investigation of temperature required to detonate RDX/TNT

The ignition point of RDX/TNT is normally taken as 193°C. This statement is arbitrary in that it refers only to the particular circumstances in which 0.05 gram of powdered RDX/TNT is heated at 5°C per minute almost without confinement. It was not expected that a closed system containing appreciable amount of explosive would necessarily detonate at this temperature, nor was it expected that this temperature could be reached with a limited heat input, especially where an explosive component could melt and dissipate the heat by convection.

Other investigations have recently been carried out to determine the effect of heat on closed explosive systems, but the data obtained were mainly for propellants or ammonium nitrate and little attention had been paid to high explosives. However the methods used were applicable to RDX/TNT systems and experiments were carried out as follows.

(a) Small scale tests

A mild steel container was prepared which consisted of a tube, of 1/4 in. internal diameter and 5 in. in length, closed at one end and opening up to a lin. internal diameter and lin. long steel tube at the open end (photograph 22). The tube was 1/8 in. thick. The open end was threaded on the outside to take a screw-on cap. The mating surfaces of the tube and cap were accurately machined. In the centre of the cap was a small steel collar about 1/2 in. diameter and 1/8 in. long. A 1/16 in. hole was drilled to a point midway between the inner and outer surfaces of the cap, its closed end being in line with the axis.

The tube was filled with RDX/TNT 60/40, the cap screwed on, and a copper washer used to ensure a good seal. The screw threads were coated with asbestos silicate cement. Into the collar was inserted a carbon rod, and a thermocouple was pushed into the small hole under the heater. The carbon rod was heated electrically using 30-50 amps at 14 volts, and the temperature at which explosion occurred and the time of heating recorded. The results are shown in Table 10.

Table 10

Heating of RDX/TNT 60/40 in steel tubes

Duration of trial (mins)	Maximum temperature °C recorded by thermocouple	Result
6	230	Mild explosion, much unspent filling
11	-	Mild explosion
11.5	223	More violent explosion, some signs of detonation.
12	208	Mild explosion
13	206	Mild explosion
13.5	247	More violent explosion, cap in 9 pieces
15	215	Good detonation, over 50 pieces
17.5	229	Mild explosion
28.5	217	More violent explosion, some signs of detonation
-	173	Mild explosion, much unspent filling

Any relation between the rate of heating and the temperature of explosion, or between the latter and the violence of the explosion is not apparent.

In this test the temperature recorded was that of the steel envelope immediately below the heater and not necessarily that of the explosive in contact with it. This might well be 5-20°C. lower.

In the next series of trials an extra thermocouple was introduced to record the temperature of the explosive at a point in the filling 1/8 in. below the heated surface of the closing cap.

Table 11

Heating of RDX/TNT 60/40 in steel tubes

Duration of trial (mins)	Maximum temperature °C recorded by thermocouple Exterior	Interior	Result
7	189	150	Good detonation, over 50 pieces
13.5	239	173,153	Mild explosion
20.25	203	154,152	Mild explosion a little unspent filling
32.25	196	171	Partial detonation, cup in 25 pieces, stem whole

(Where two temperatures are given, the last is the temperature at the time of explosion, the temperature having dropped from the maximum). Typical fragments from these trials are shown in photograph 23.

The duration of these experiments was sufficient for much of the explosive to have melted, and presumably for convection to occur, but in spite of this the difference in temperature between the two thermocouples is marked.

A further trial was carried out in which the position of four thermocouples was determined by radiography (photographs 25, 26). The first thermocouple (A) was in the steel tube below the heater as before, the second (B) was inside the tube at the surface of the explosive, the third (C) and fourth (D) 1/8 in. and 1/4 in. below the surface. The temperature record for this trial is shown in figure 11. After 13.75 minutes a partial detonation occurred. The energy input was maintained at a constant value during the trial and it was observed that both thermocouples B and C showed a marked decrease in temperature after approximately 10 minutes heating. Thermocouple D, the temperature of which lagged well behind, did not show this decrease. This type of curve is repeatable, and it was found that after this decrease, the rate of rise of thermocouple C was much greater than would be accounted for by the external heat input. The suggestion is that the discontinuity in the curve indicates the commencement of decomposition of the explosive filling under the particular conditions and that this decomposition increases in vigour until an explosion or detonation occurs.

Presumably the decomposition starts in a very local manner where the explosive is hottest and owing to the uncertainty in positioning of the thermocouples it is not possible to state precisely the temperature of the explosive where the reaction starts. It is, however, clear that this is above 150°C. and further experiments will be carried out to clarify this point.

It is sufficient for the purpose of this report to have shown that in this system detonation of RDX/TNT can occur by heating the exterior to temperatures as low as 196°C., or a mild explosion at 173°C. It is also clear that explosion may occur before the whole system is heated to this temperature, and in fact with the times and temperatures shown, much of the explosive in the tube will be unmelted.

(b) Tests in 5.5 in. shell

A technique for heating the fillings of 5.5 in. shell had already been used in other investigations (A.R.E. and E.R.D.E. joint report No.1). A diagram of the arrangement is shown in Fig.12.

Three 5.5 in. shell were filled with RDX/TNT (cast), closed with 500 lb. bomb exploder containers, and fitted with a thermocouple internally near the central region of the exploder container. They were heated at varying rates by means of an electric element in the exploder container. Violent explosions were obtained in each case. The results are shown in Table 12.

Table 12

Heating of RDX/TNT 60/40 in 5.5 in. shell

Heat input (watts)	Time to explosion min	sec	Maximum temp. recorded °C	Result
1237	1	45	-	Explosion with red flash. Nose fragmented, rest of shell broken. (Photograph 24, round 6)
770 (intermittent)	11	20	167	Explosion. Good fragmentation. No flash much grey-black smoke.
375	11	54	148	Bright flash, dark smoke, probably detonation. Very small fragments. 200 yd. throw. (Photograph 24, round 8)

A graph of the temperature record of the last two trials is shown in Fig.13.

The temperature records in these experiments are not as reliable as in the small scale tests, and it may well be that some portion of the explosive was at considerably higher temperature than that recorded by the thermocouples.

It is apparent therefore that RDX/TNT in a closed system can be made to detonate if a sufficient local heat input is maintained, without the necessity to raise the whole of the explosive to its ignition point.

4.5 Investigation of temperature rise caused by friction of trolley tyre on steel

(a) Laboratory tests

An apparatus (photograph 27) was set up to rotate pieces of bomb trolley tyre against a mild steel plate. The tyre was mounted on the face of an aluminium disc rotated at approximately 60 r.p.m. The tyre pressed on a 3/8 in. thick mild steel plate, immovable in the direction of rotation, but which could be pressed on to the tyre by a worm acting via a statimeter. A thermocouple was placed on the back of the plate at the position of maximum temperature. The temperature rises obtained were plotted (Figs.14-16), and it is obvious that the temperature can be reached at which RDX/TNT would detonate. An interesting point is that the Dunlop tyres heat the plate up much more slowly than the other two makes, and it was observed that melting of the rubber occurred in this case, whereas the other tyres remained dry and were abraded away as a fine powder.

(b) Full scale tests

In the laboratory tests, the tyre specimen was a rotating disc on the end of a shaft. The central portion was therefore less effective in producing friction than the outside and a comparison with the frictional area observed in the Marham experiments suggested that a full scale test would be approximately 15 times as efficient in heat production. Experiments at Glascoed (ARD 387/42) had shown that friction of a dilly wheel on an empty powder container weighted with 550 lbs. produced the following temperatures. (Dilly run at 4 m.p.h.)

Table 13

Temperature reached from friction of dilly wheel

Distance (yards)	Temperature °C
20	85
50	145
90	190
150	190

This compares with experiments carried out at No.3 M.U. by D.A.I.S. to determine the heat transmitted to the inside of a 500 lb. bomb casing by rubbing of a tyred wheel.

Table 14

Temperature produced by friction of tyre on 500 lb. bomb

Load on tyre	Speed m.p.h.	Starting temperature °C.	Maximum temperature °C.	Maximum rise in temp. °C	Distance for maximum rise yards
228	2.4	10	100	90	610
228	4.7	65	150	85	1170
328	5.4	10	170	160	890
328	10.5	30	130	160	100
328	10.7	36	200	164	190
			210	174	1450
378	10.9	45	220	175	890
>378	10	80	250	170	1030
>378	10	110	250	140	100
			290	180	890

In the Marham incident it was reasonably certain that the port bomb was subject to friction for at least 80 and at the most 450 yards. It is not possible to give an accurate estimate of the operative weight on the trolley tyre, but taking into account the positions assumed by the bombs in the experiments at Marham, it is probable that it was at least half the weight of a 1000 lb. bomb and, if any wedging action took place or the weight of the second bomb was not fully supported on the frame, it could be considerably more. It would appear quite reasonable therefore to expect the temperature of the bomb to have risen to dangerous limits during the latter part of the towing.

A framework was constructed (Figure 17) on which a 1000 lb. bomb could be suspended by the nose so that the weight of the rear portion was taken on a tyred trolley wheel. The trolley wheel could be rotated by an electric motor either at 130 or 260 r.p.m., corresponding to a ground speed of 6.7 or 13.5 m.p.h. The bomb was prevented from bouncing off the wheel by angle girders, and from axial rotation by fixing the lug.

The first experiments were made with an empty Mark 2 bomb, thermocouples being positioned on the inside wall which was machined smooth immediately above the area of contact with the tyre. The temperature recorded by the thermocouple on rotation of the wheel using a Firestone tyre, was 170°C. in 30 seconds, 208°C in 1 minute, and 250°C. in 2 minutes at 130 r.p.m. At 252 r.p.m. 290°C. was attained in 1 minute. Smoke was emitted above 170°C. and at 250°C. the rubber powder abraded from the tyre began to glow red.

The high temperature was extremely local, a drop of 100°C occurring within an inch of the centre of the contact area at the end of two minutes. This high temperature gradient prevented any temperature measurements being made on the outside of the bomb as the thermocouple could not be placed sufficiently close to the hot spot.

The results of further experiments in which 300 lb. weight was attached to the bomb to represent filling are shown in Table 15 and plotted in Fig.18.

Table 15

Temperature of inside wall of 1000 lb. Mark 2 bomb rubbing on tyre (°C)

	Firestone tyre			Dunlop tyre		
	1	2	3	4	5	6
Time (Secs)	Tyre pressure unknown	Tyre pressure 39 p.s.i.	Experiment 2 continued after 2 minutes pause.	Tyre pressure 37 p.s.i.	Tyre pressure 37 p.s.i.	Experiment 5 continued after 2 minutes pause.
0	20	40	160	25	32	121
10	68	84	184	64	70	137
20	118	150	225	104	115	150
30	Valve	190	262	126	140	165
40	torn out	224	295	140	165	177
50	of inner	245	318	150	178	185
60	tube	264	335	155	190	190
80		280	350	164	201	195
100		Thermo-	Excessive	170	205	199
120		couple	smoke.Rubber	176	212	202
		worked	powder on			
		loose	fire			

After test 3 it was observed that the inside of the bomb was blued over a radius of 1.5 in. In test 4-6 the rubber of the tyre melted and the resultant lubrication kept the temperature down to a maximum of about 210°C. Once the rubber has melted it does not resolidify.

It is clear therefore that such friction could raise the temperature of the RDX/TNT inside a bomb to that at which detonation would occur, and to illustrate the point the experiment was repeated with a filled Mark 7 bomb.

The apparatus was set up at Shoeburyness with a 1000 lb. Mark 7 bomb filled RDX/TNT 60/40 placed in position. This bomb contained three thermocouples on the inside approximately 1.5 inches apart, and it was arranged so that they were at the area of contact with the tyre. A Firestone tyre was used, driven at 132 r.p.m. ≡ 6.7 m.p.h. ground speed. (Photographs 28-30). The wheel was started by remote control, but did not turn until the third attempt. This was due to strain in the apparatus, the bomb moving slightly forward and jamming the wheel. At the third attempt the direction of rotation was reversed, and a little mud smeared on the tyre to assist starting. After 30 seconds, smoke was seen to be issuing from the tyre and this continued until at 2 minutes 10 seconds the bomb detonated. The size of the crater was 15 ft. diameter and 6 ft. deep (photograph 31) and the apparatus was completely destroyed. The fragments recovered are shown in photograph 32.

The temperature rise shown by the thermocouples was plotted and is shown in Fig.19. A first straight portion occurred while the mud was being removed from the tyre. The characteristic drop in temperature occurred after approximately one minutes effective heating, at an unusual low temperature which indicates that thermocouples 2 and 3 were not in the region of maximum reaction. Thermocouple 1 showed no drop in temperature and the rapid rise suggests that this thermocouple was in contact with the bomb wall at the region of maximum temperature and that the explosive melted away, leaving it surrounded by an air or gas pocket. The temperature subsequently recorded was that of the bomb wall due to friction plus heat of decomposition rather than that of the explosive.

At Marham, friction was known to be occurring for 80 yards. Assuming a speed of 5 m.p.h. this is approximately half a minute, in which case the temperature would have reached the danger point, but the total heating time is rather short. If it can be assumed that friction occurred across runway 20 from the point where the driver examined the bombs, the time is ample (230 yards at 5 m.p.h. or 94 seconds), since the time of waiting on the far side of runway 20 must also be included, for once a certain stage of decomposition of the RDX/TNT has been reached the reaction will be self supporting.

5. Conclusions

From the evidence available the Court of Inquiry came to the conclusion that the most probable cause of the accident was friction generated by the rear port wheel of the trolley rotating against the port bomb. The evidence obtained in this investigation fails to suggest any other cause, and the conclusion reached by the Court has been supported by laboratory experiments culminating in a reproduction of the actual incident.

6. Acknowledgements

The following acknowledgements are due for assistance given in the investigation.

Commanding Officer, R.A.F. Marham

D.C.I.	C.Arm.O., H.Q. Bomber Command
S.P.E.E.	Sec.O.B.
D.I.Arm.	D.Arm.Eng.

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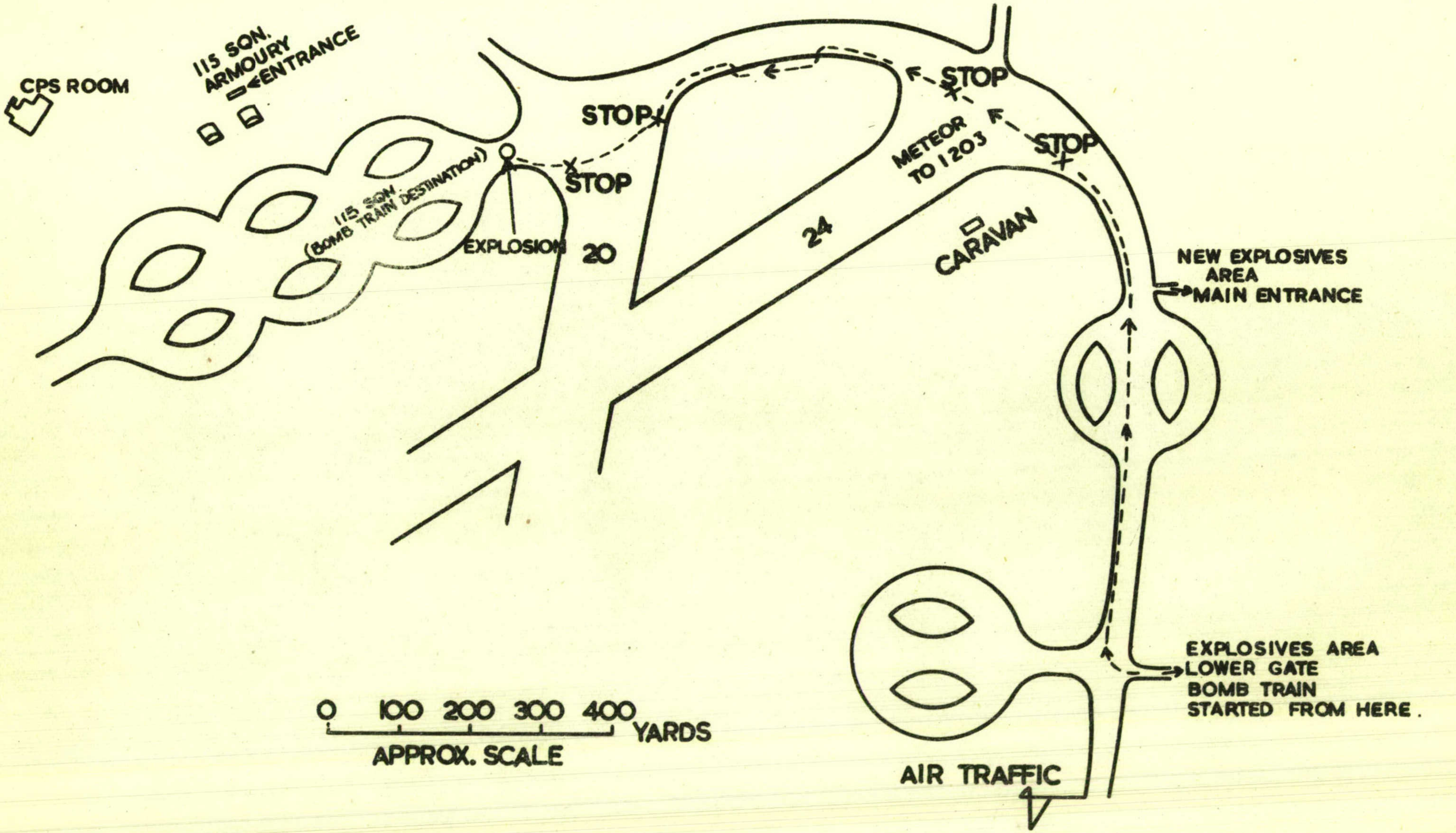

FIG. 1 GROUND PLAN OF BOMB INCIDENT, MAR. RAF. 2846 2ND. OCT.'54

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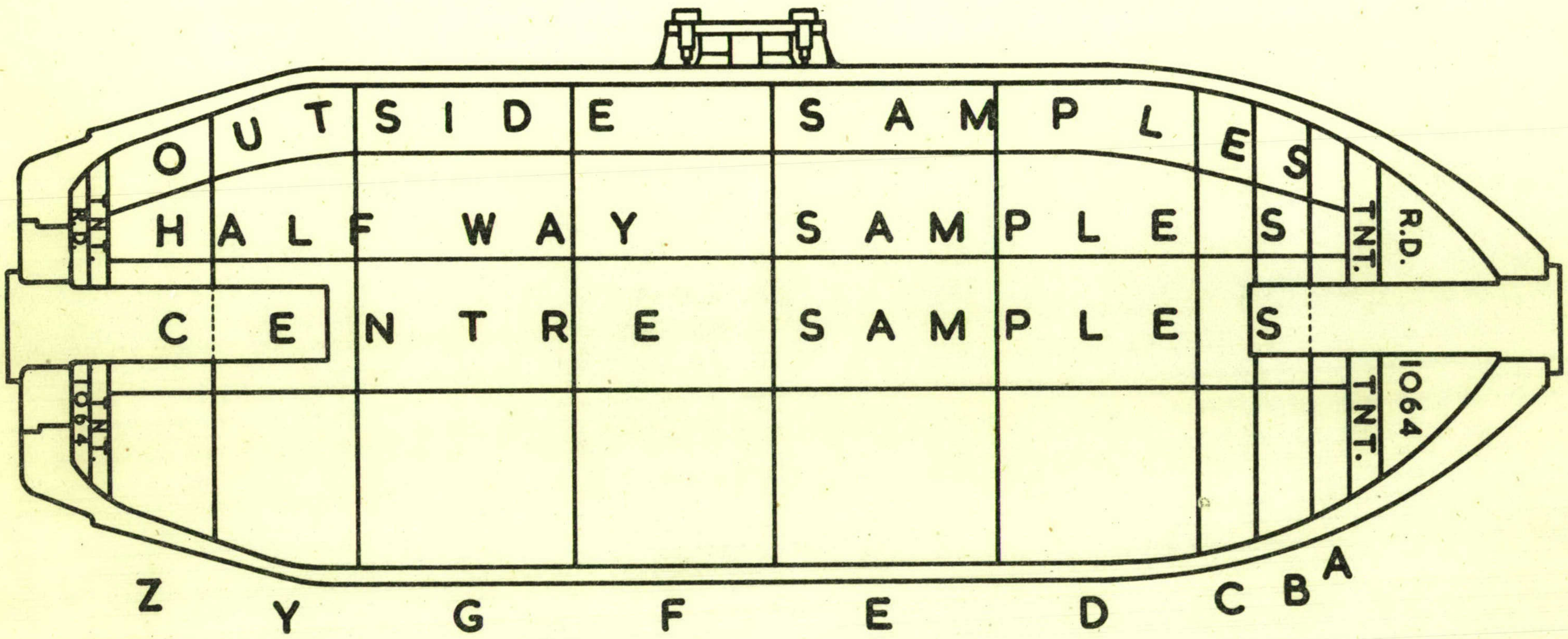
FIG. 2. PLAN SHOWING WHERE PIECES WERE TAKEN FROM BOMBS.



SCALE 1:5

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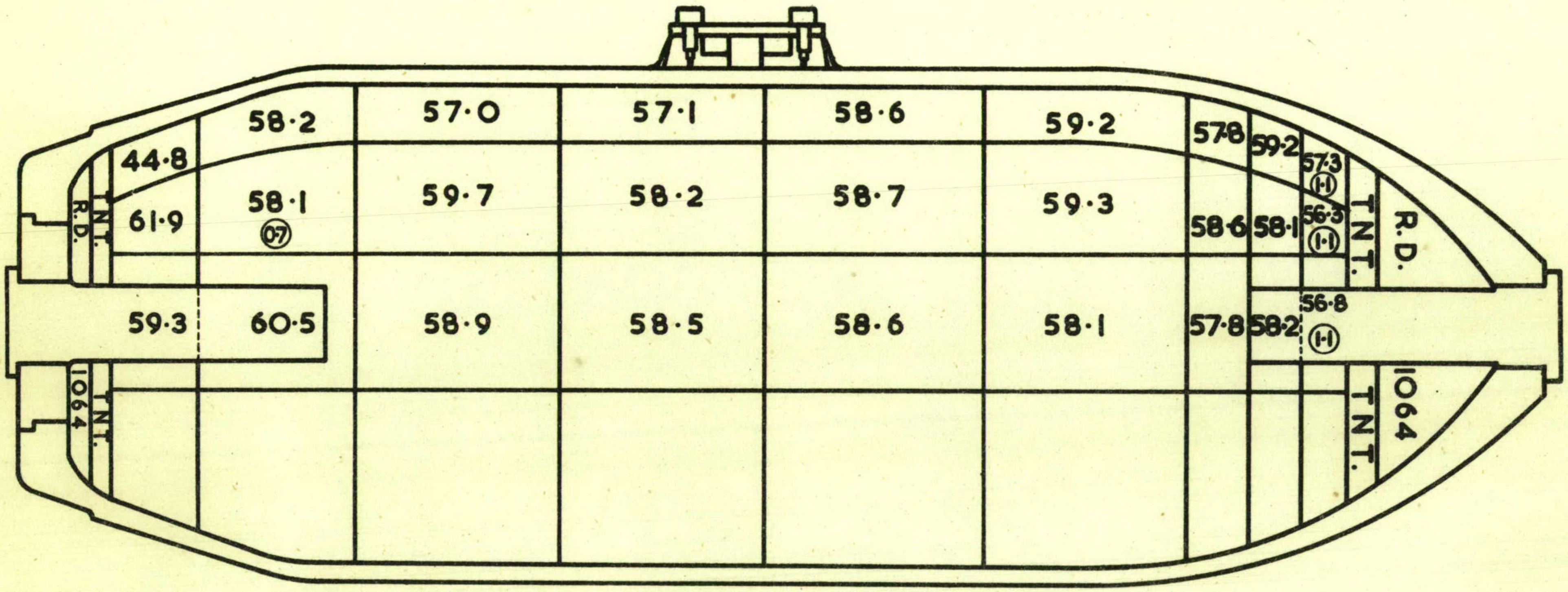
FIG. 3 ANALYSIS OF FILLING. BOMB 72.



RINGED FIGURES % BEESWAX.

OTHERS % RDX

SCALE 1:5

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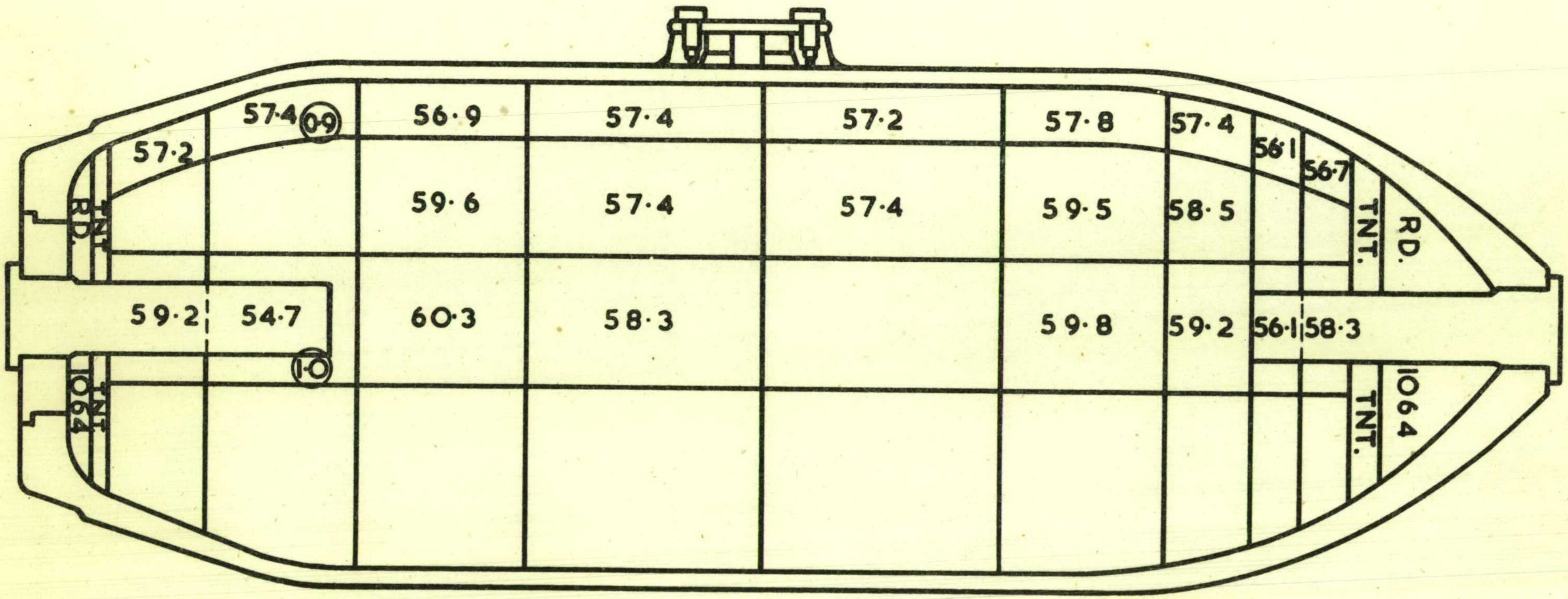
FIG. 4 ANALYSIS OF FILLING. BOMB 106.

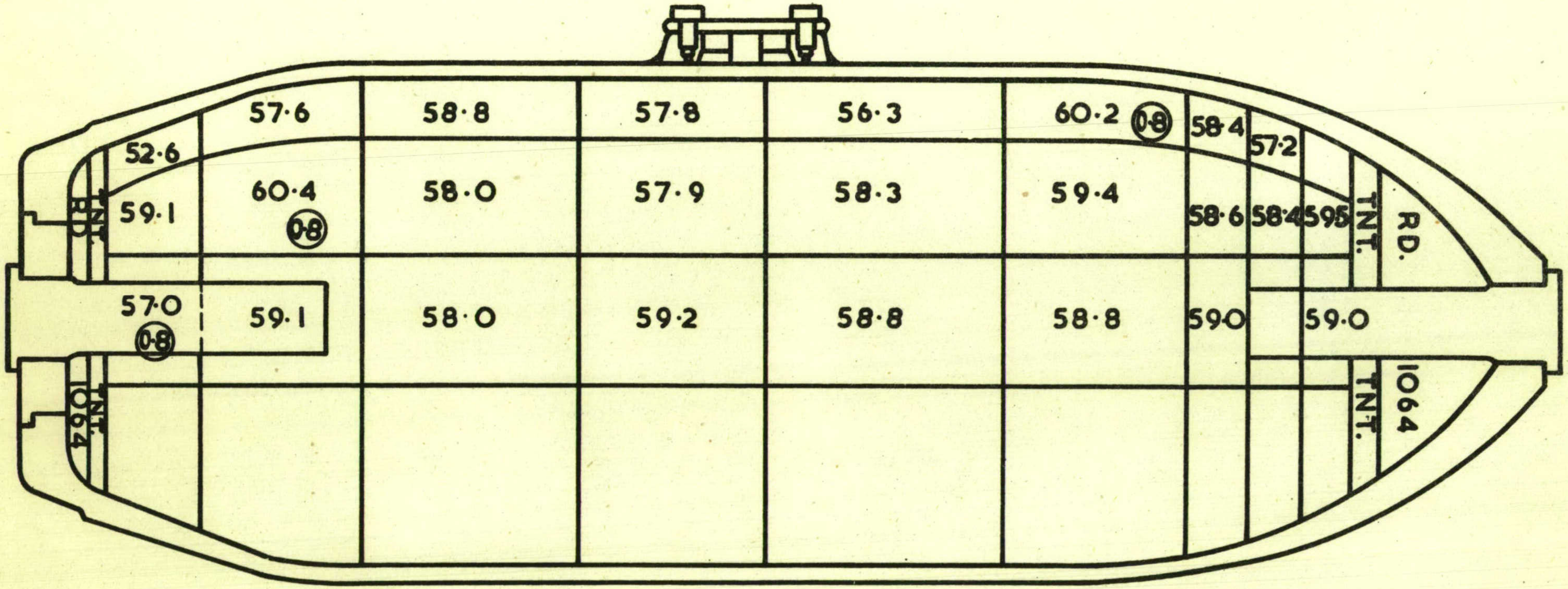


RINGED FIGURES % BEESWAX.

OTHERS % RDX.

SCALE 1:5

FIG. 5 ANALYSIS OF FILLING BOMB 126.



RINGED FIGURES % BEESWAX.

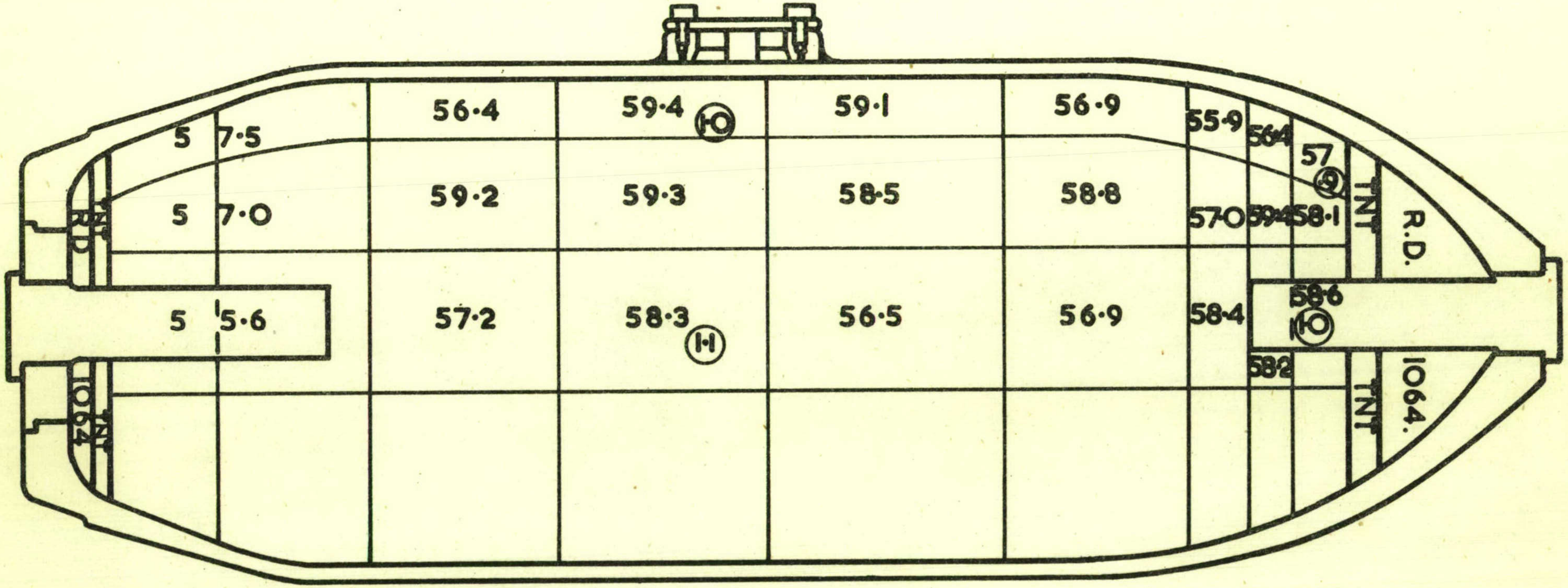
OTHERS % RDX.

SCALE 1:5

SECRET.

SECRET

FIG. 6. ANALYSIS OF FILLING. BOMB 174.

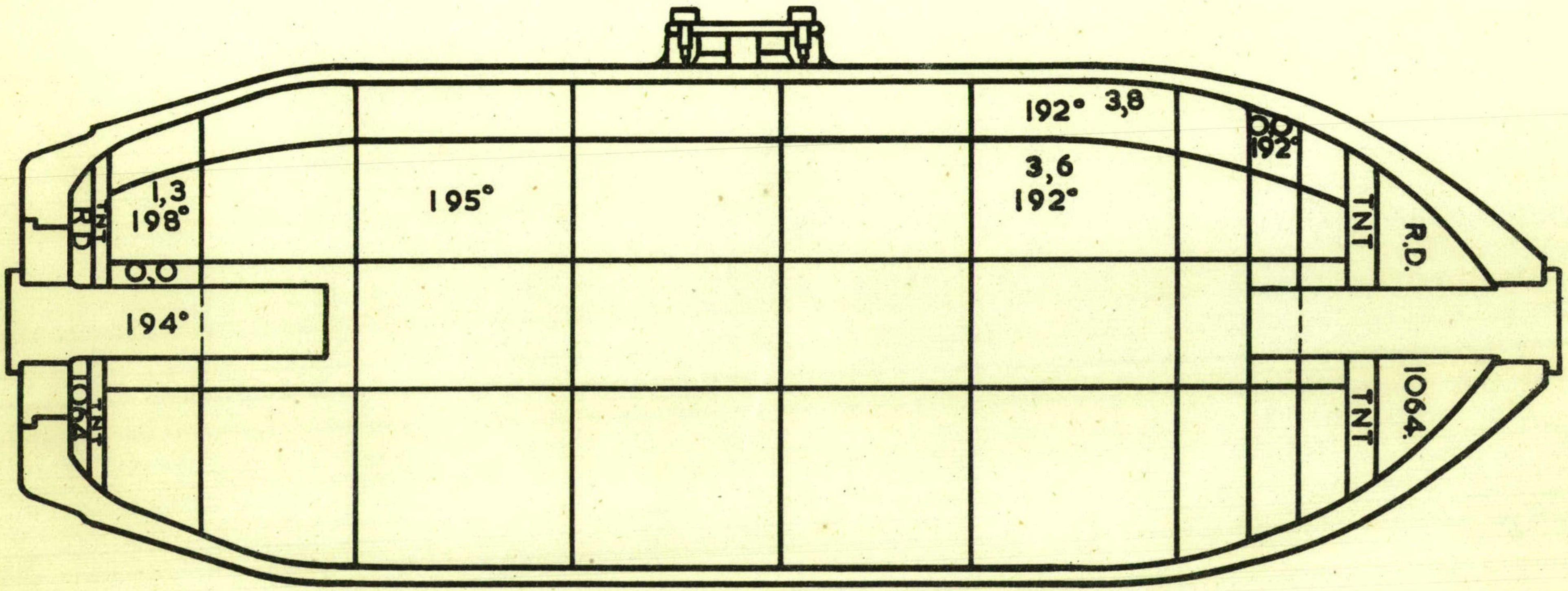


RINGED FIGURES % BEESWAX.

OTHERS % RDX.

SCALE 1:5

FIG. 7 IGNITION POINTS IN °C BOMB 72

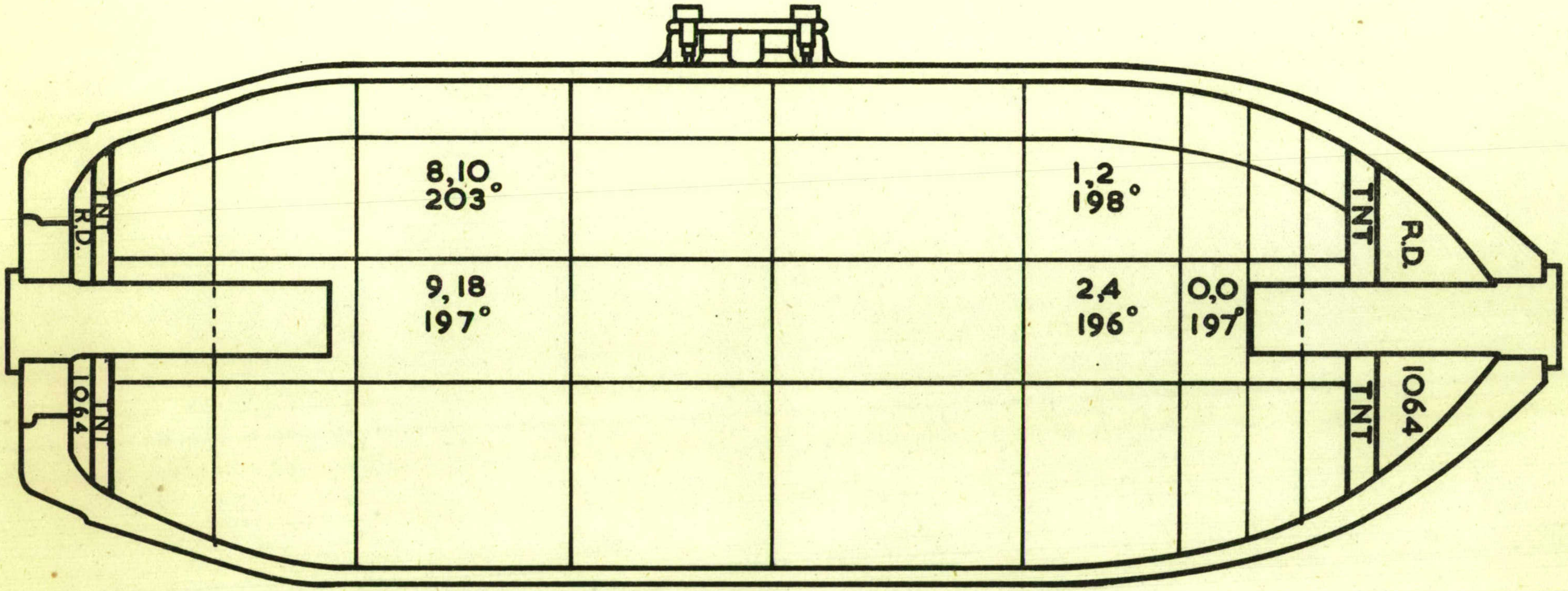


SENSITIVITY:

NO. OF IGNITIONS TOTAL GAS C.C. SCALE 1:5.

SECRET

FIG 8 IGNITION POINTS IN °C. BOMB 106.



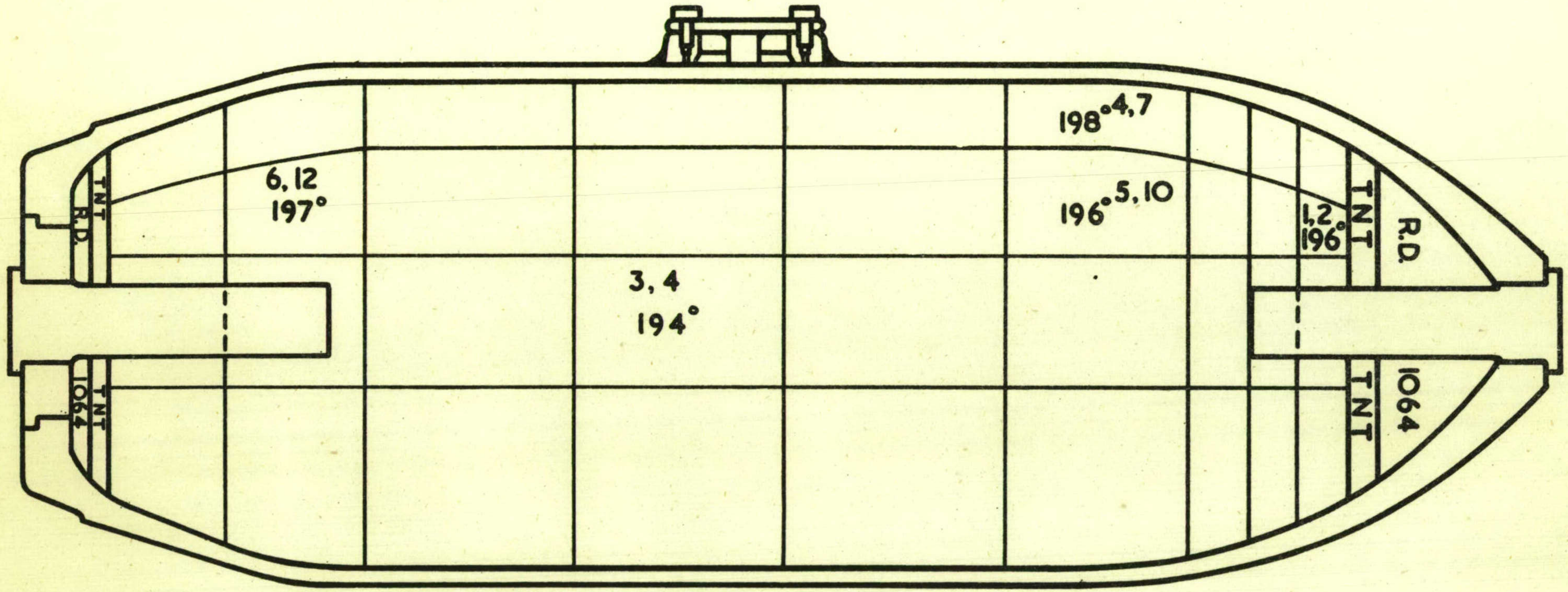
SENSITIVITY:

No. OF IGNITIONS, TOTAL GAS C.C.

SCALE 1·5

SECRET

FIG. 9. IGNITION POINTS IN °C BOMB 126.



SENSITIVITY:

No. OF IGNITIONS, TOTAL GAS C.C.

SCALE 1:5

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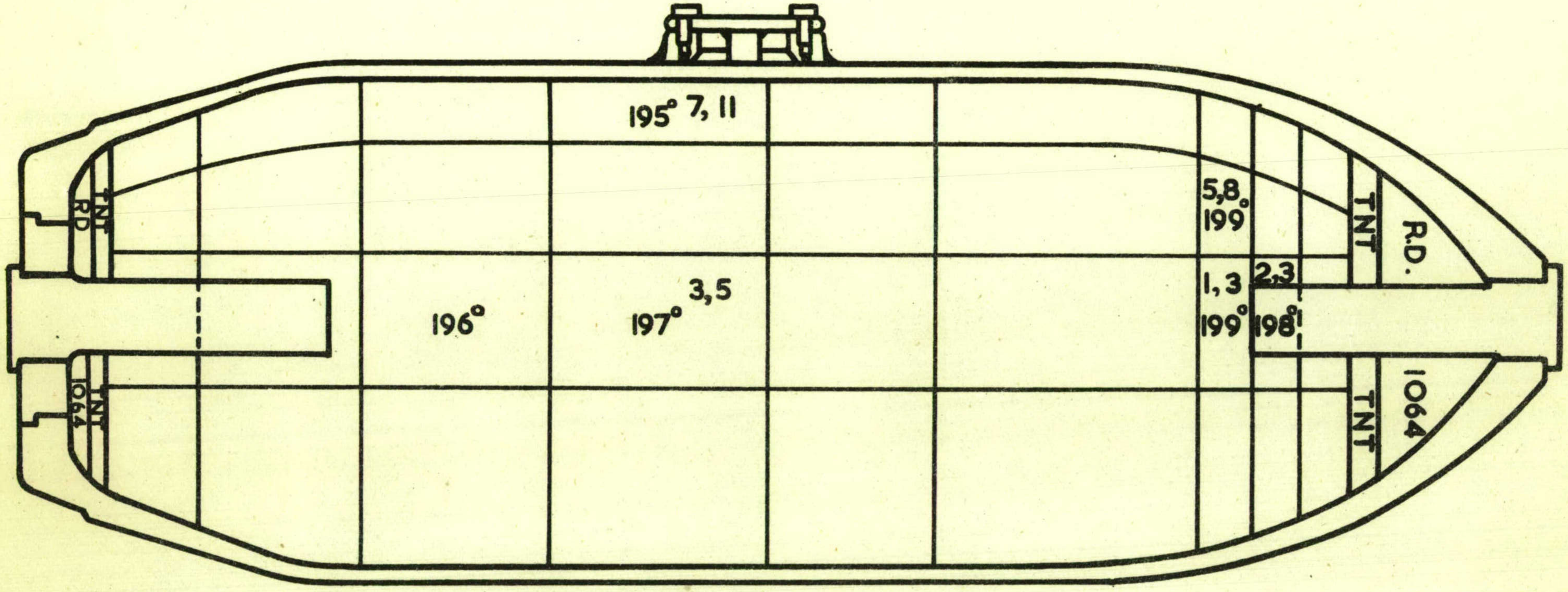
FIG 10 IGNITION POINTS IN °C

BOMB 174



SENSITIVITY:

No. OF IGNITIONS, TOTAL GAS C.C.

SCALE 1·5

FIG 11. SMALL SCALE HEATING TRIAL — RDX / TNT IN STEEL TUBES.

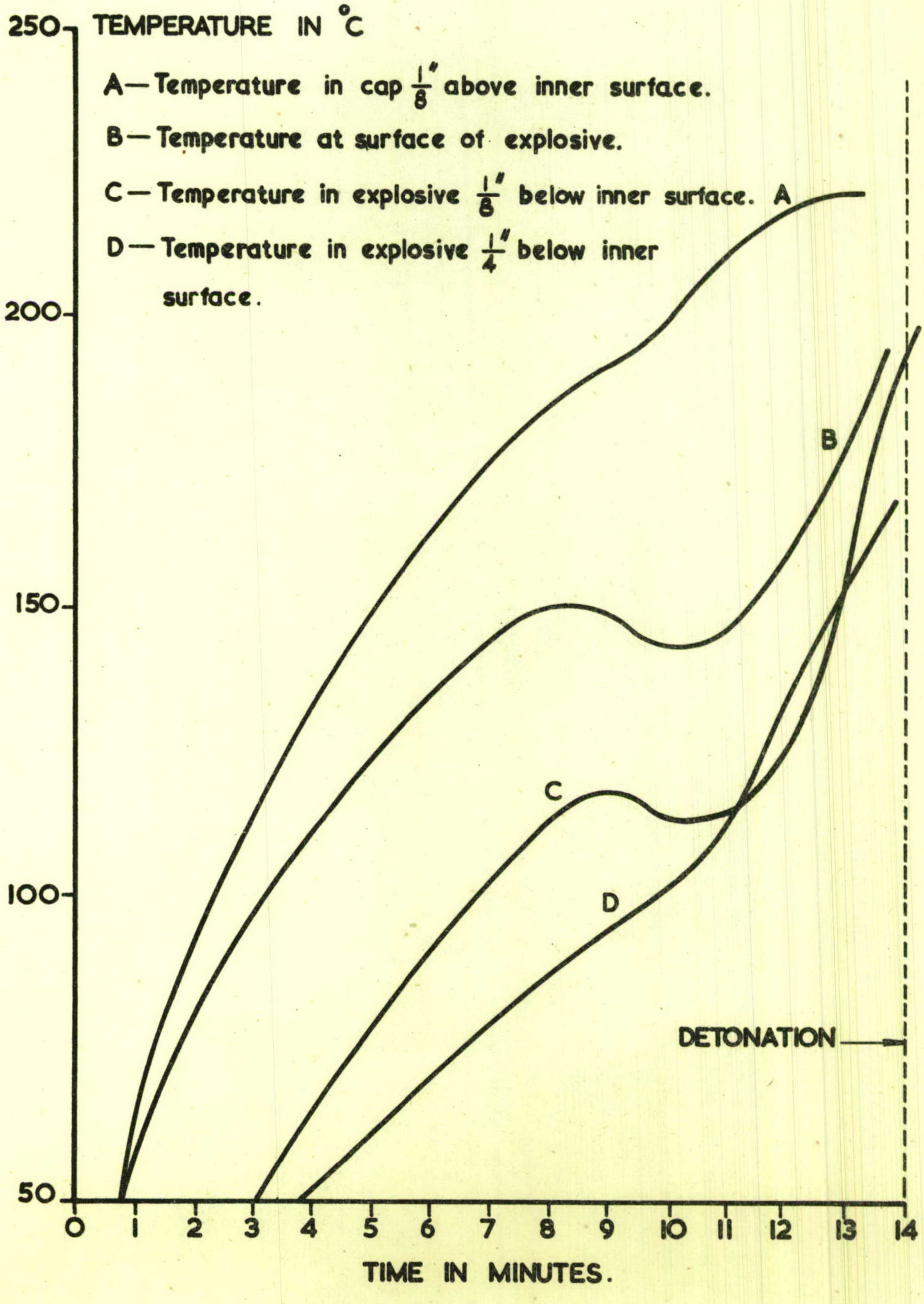


FIG. 12.

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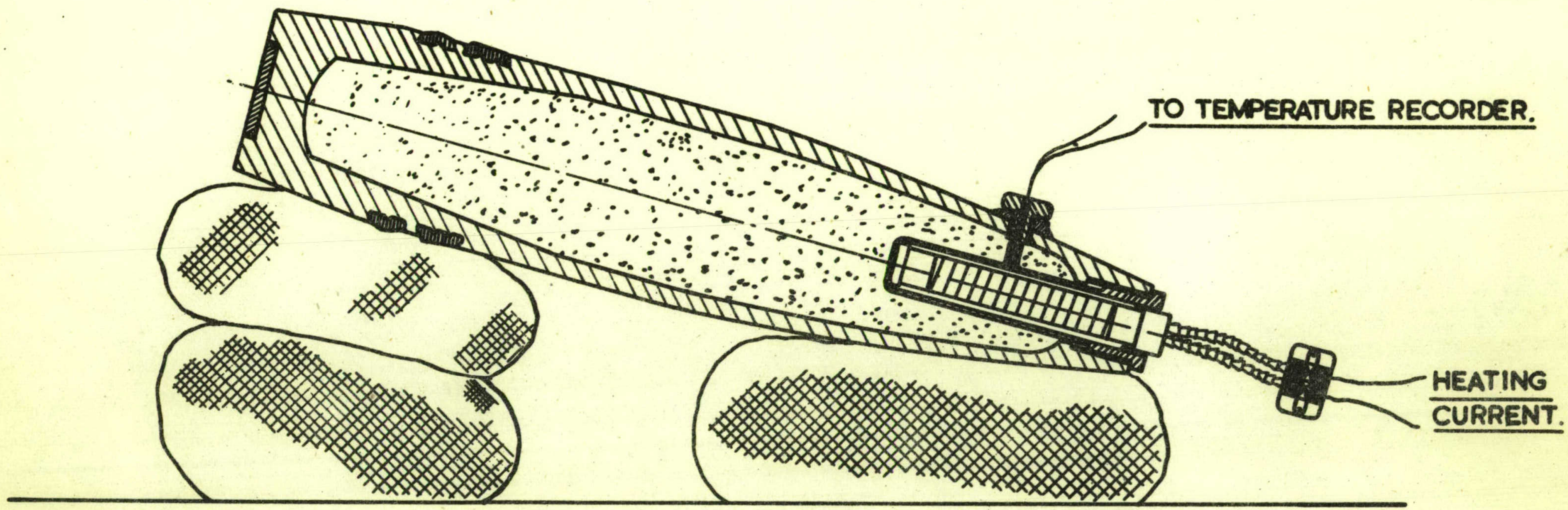
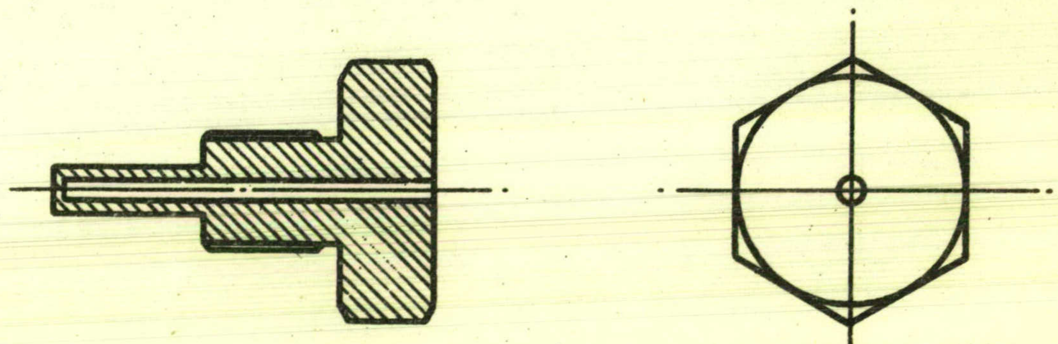


SCALE:- 1/4.



THERMO-COUPLE FITTING (FULL SIZE.)

FIG. 13. HEATING TRIAL — R.D.X/T.N.T. IN 5·5" SHELL.

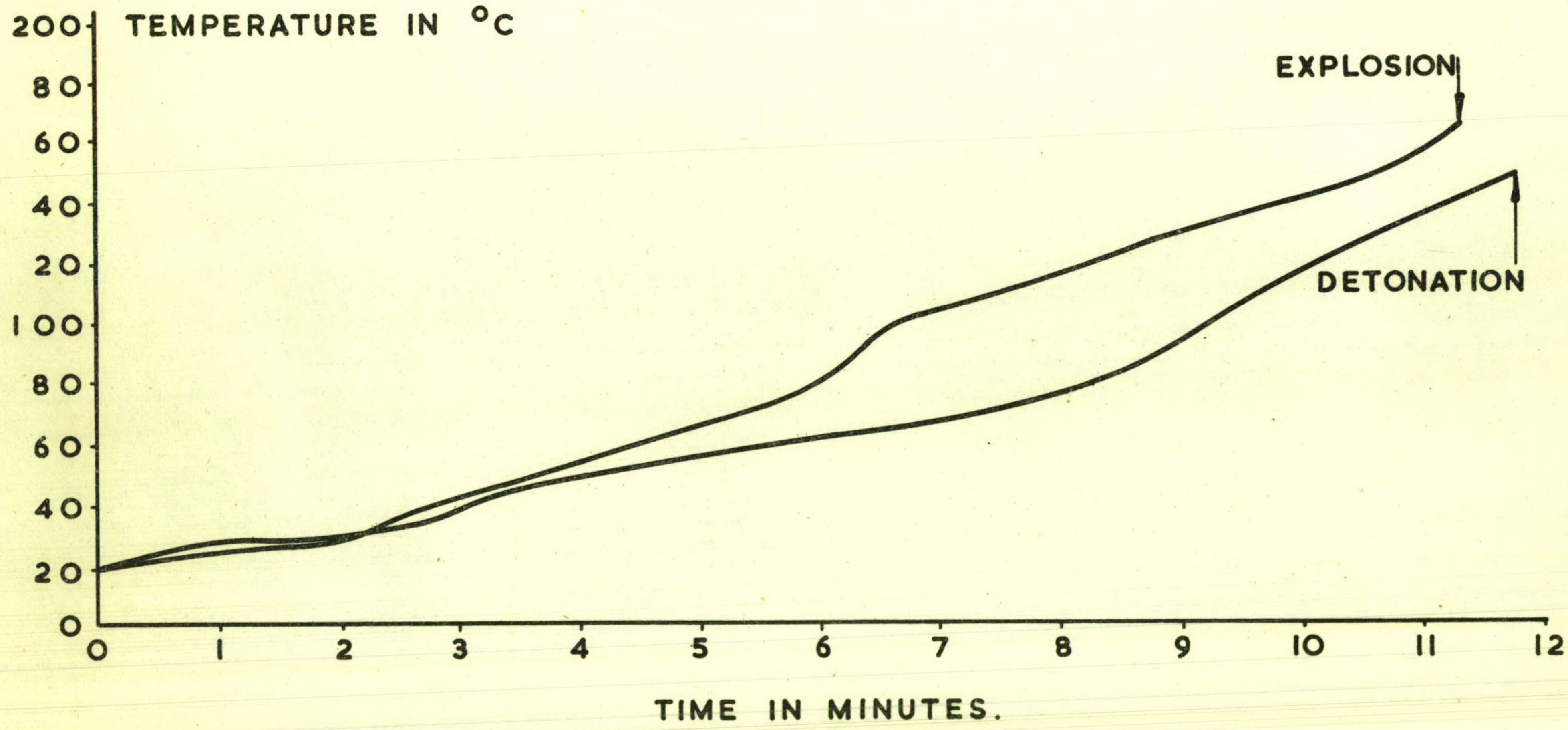


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FIG. 14. LABORATORY FRICTION TRIALS

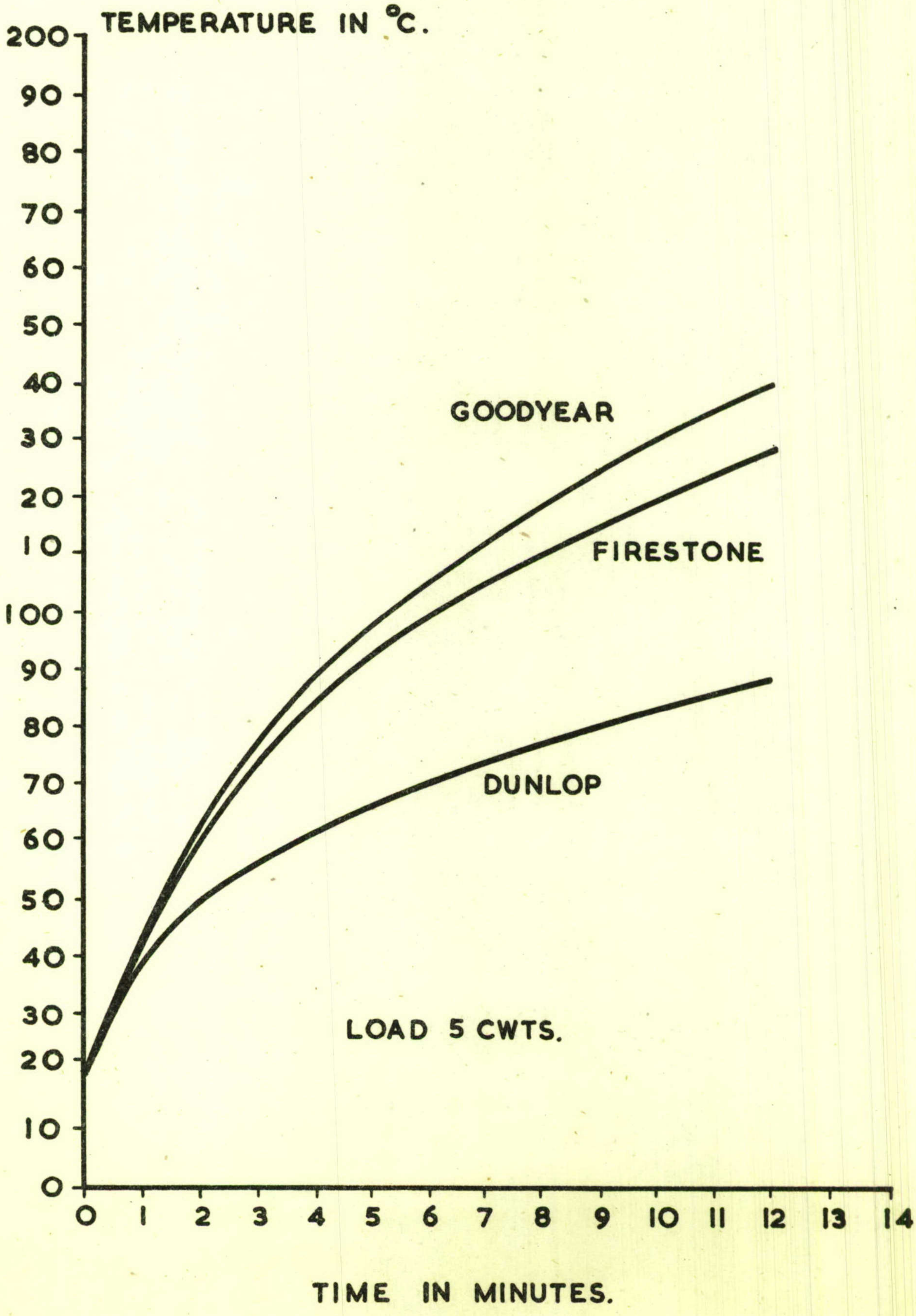

FIG. 15. LABORATORY FRICTION TRIALS

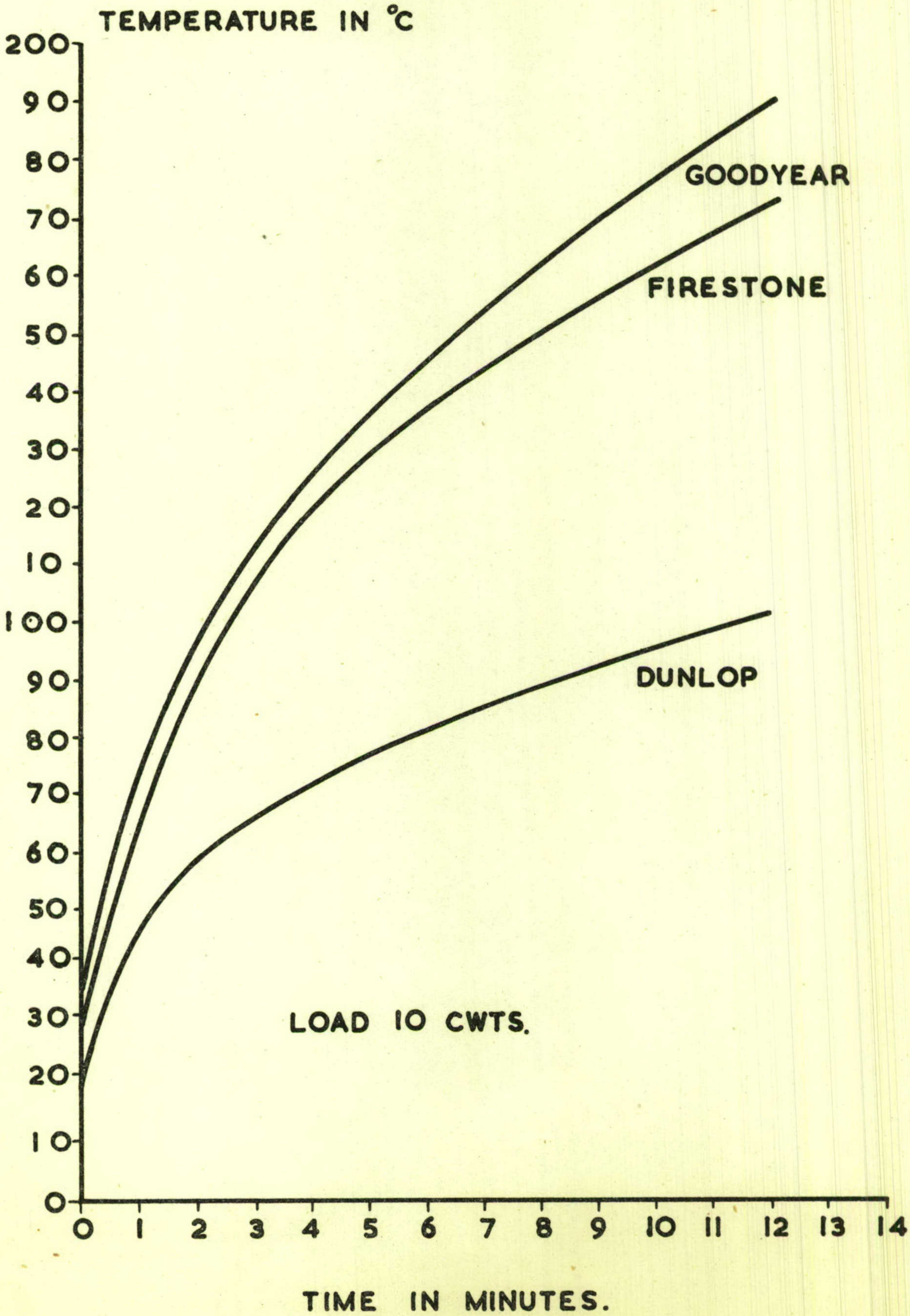

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FIG. 16. LABORATORY FRICTION TRIALS.

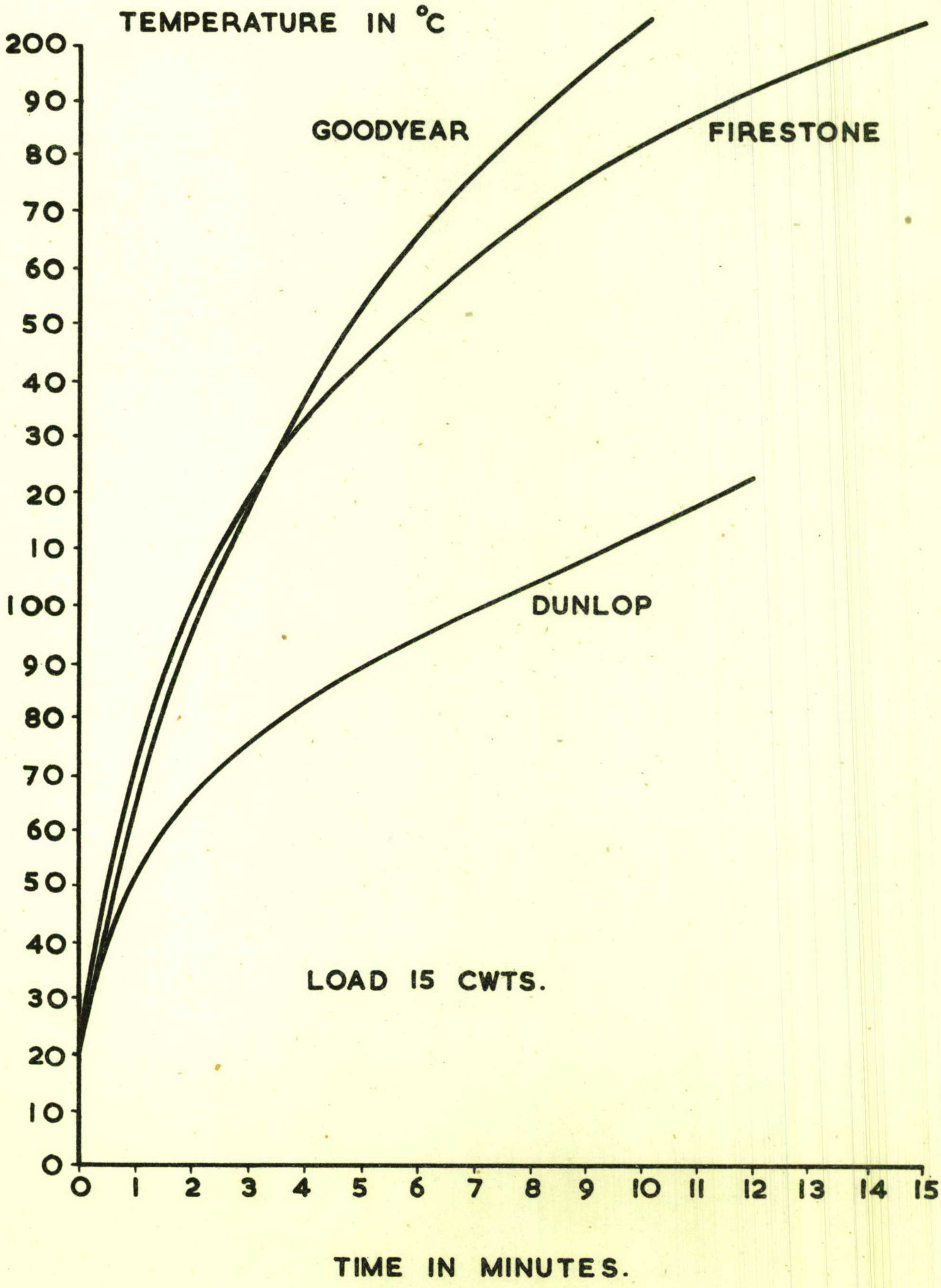

FIG. 17. TRANSMISSION TEST UNIT.

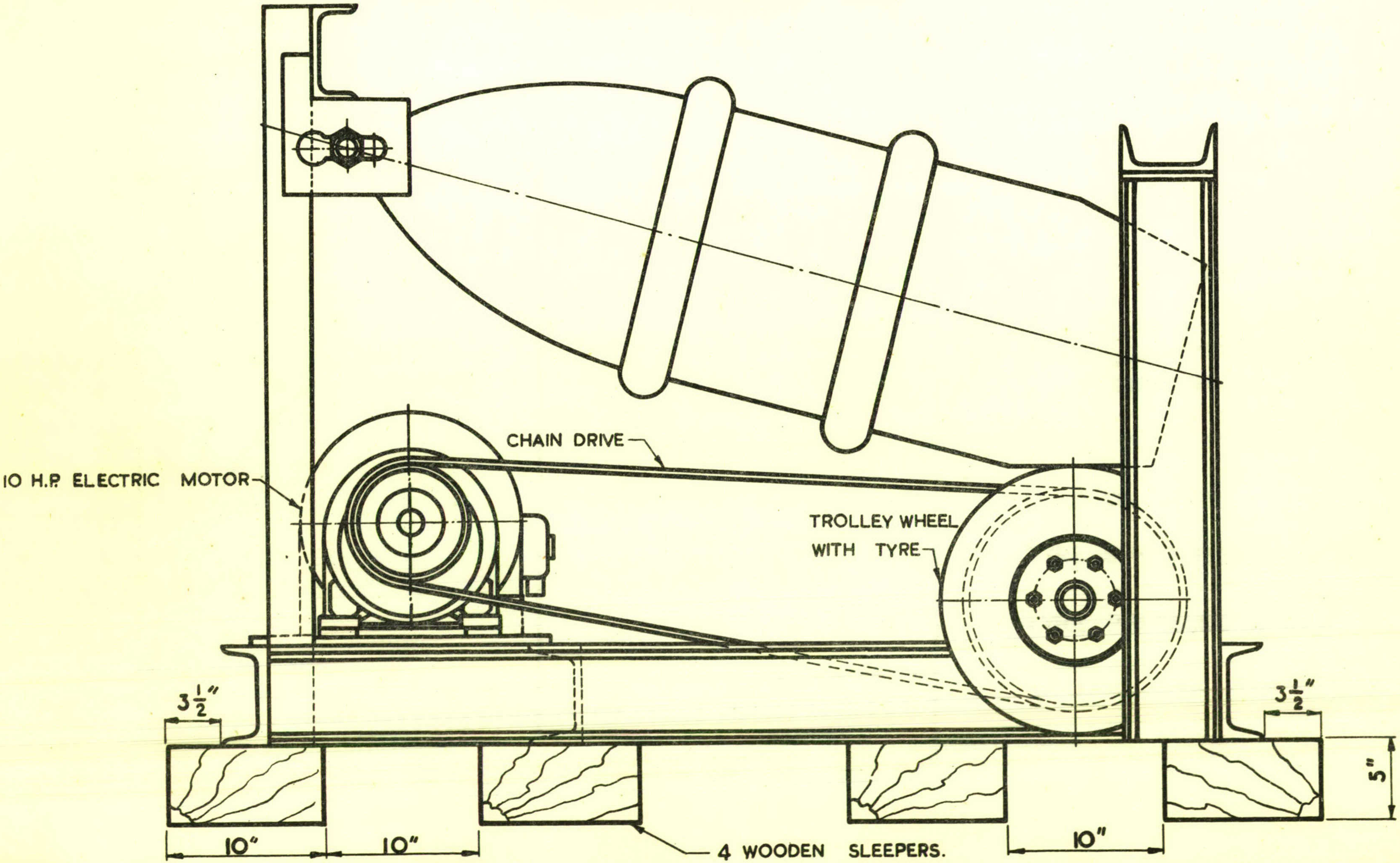

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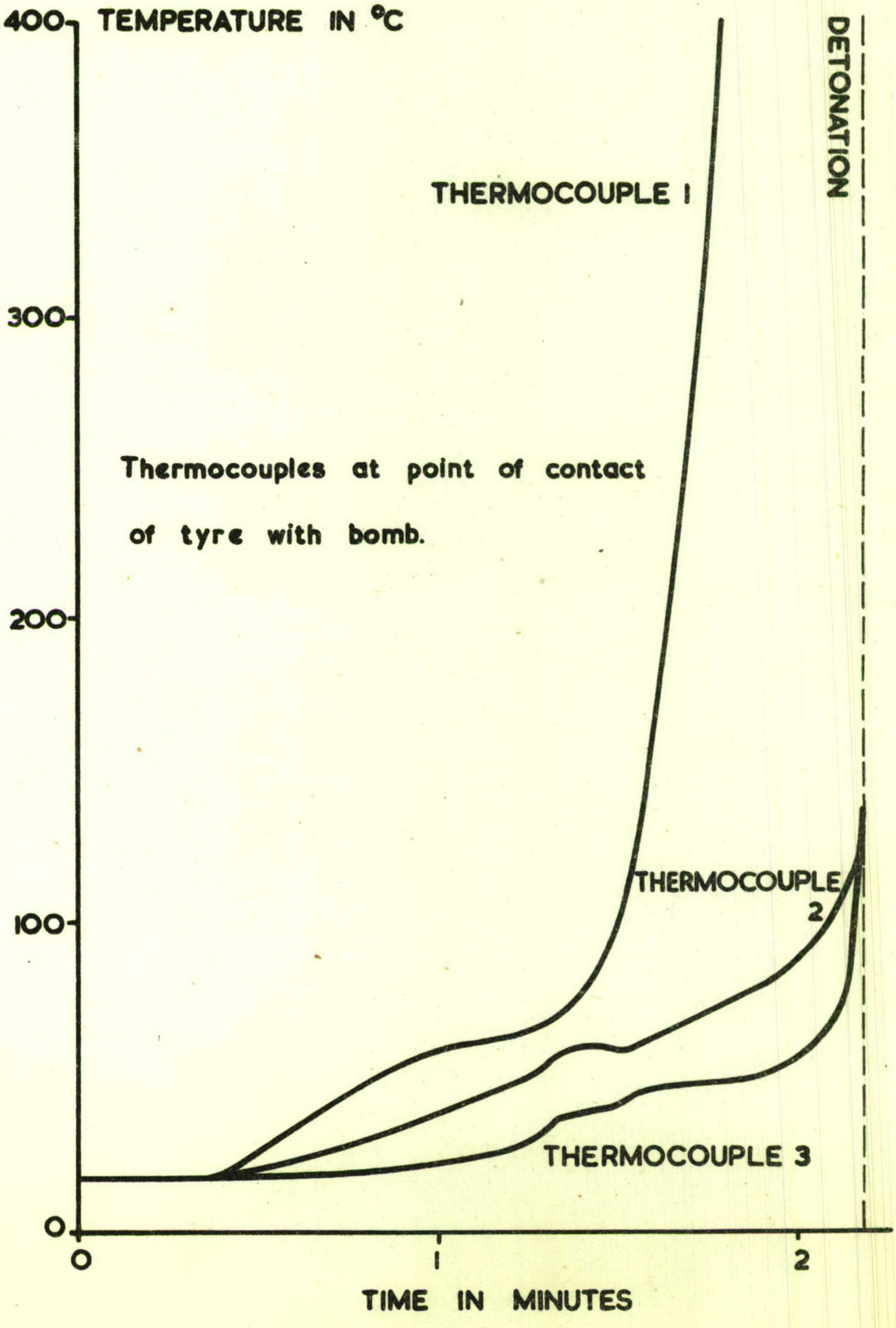
FIG. 19 FULL SCALE FRICTION TRIAL.

FIRESTONE BOMB TROLLEY TYRE ROTATING AT 132r.p.m. AGAINST 1000 lb., MC Mk VII BOMB FILLED RDX./T.N.T.



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1. Fragments of bomb recovered after the explosion at Marham

2. Fragments of bomb recovered after the explosion at Marham

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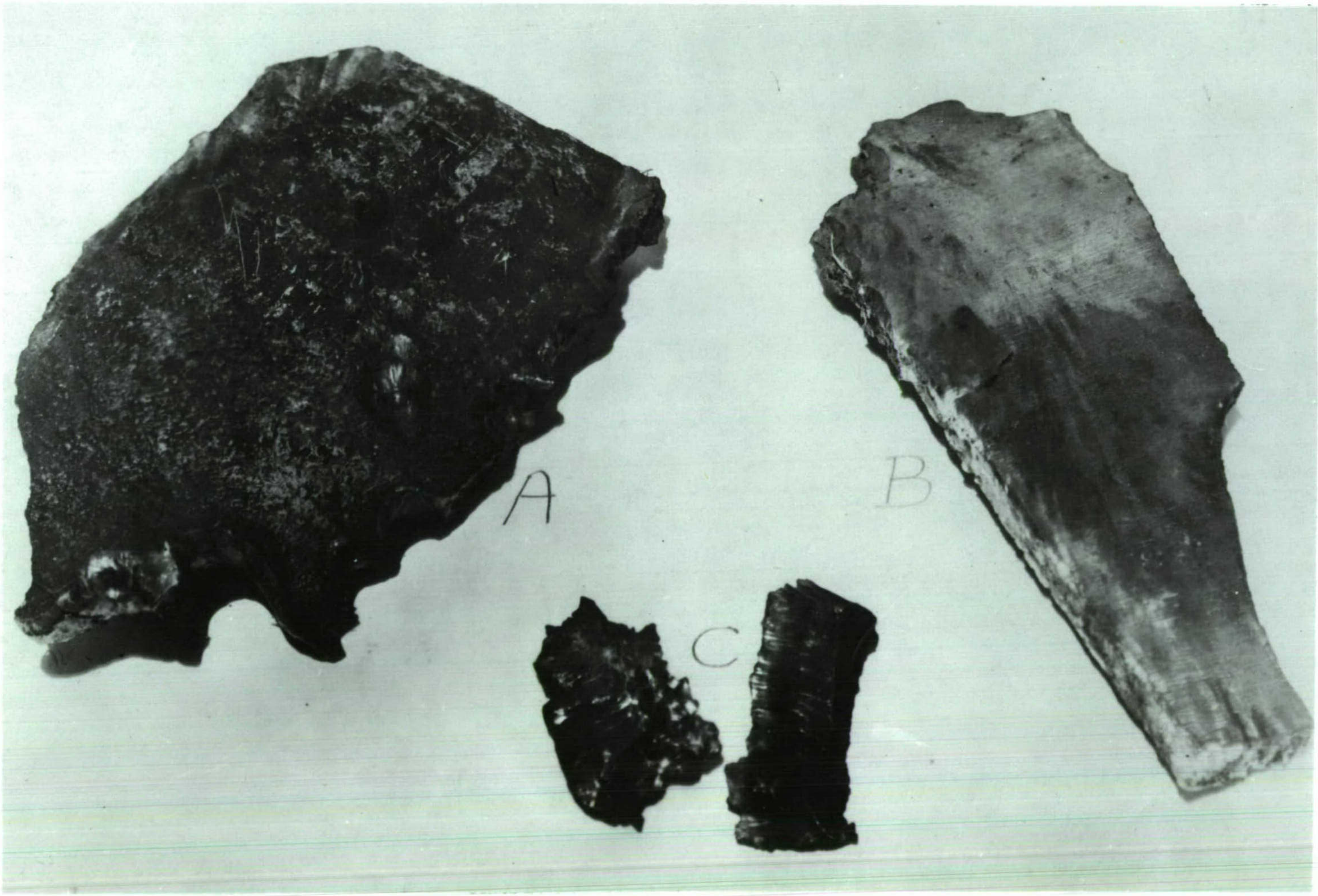
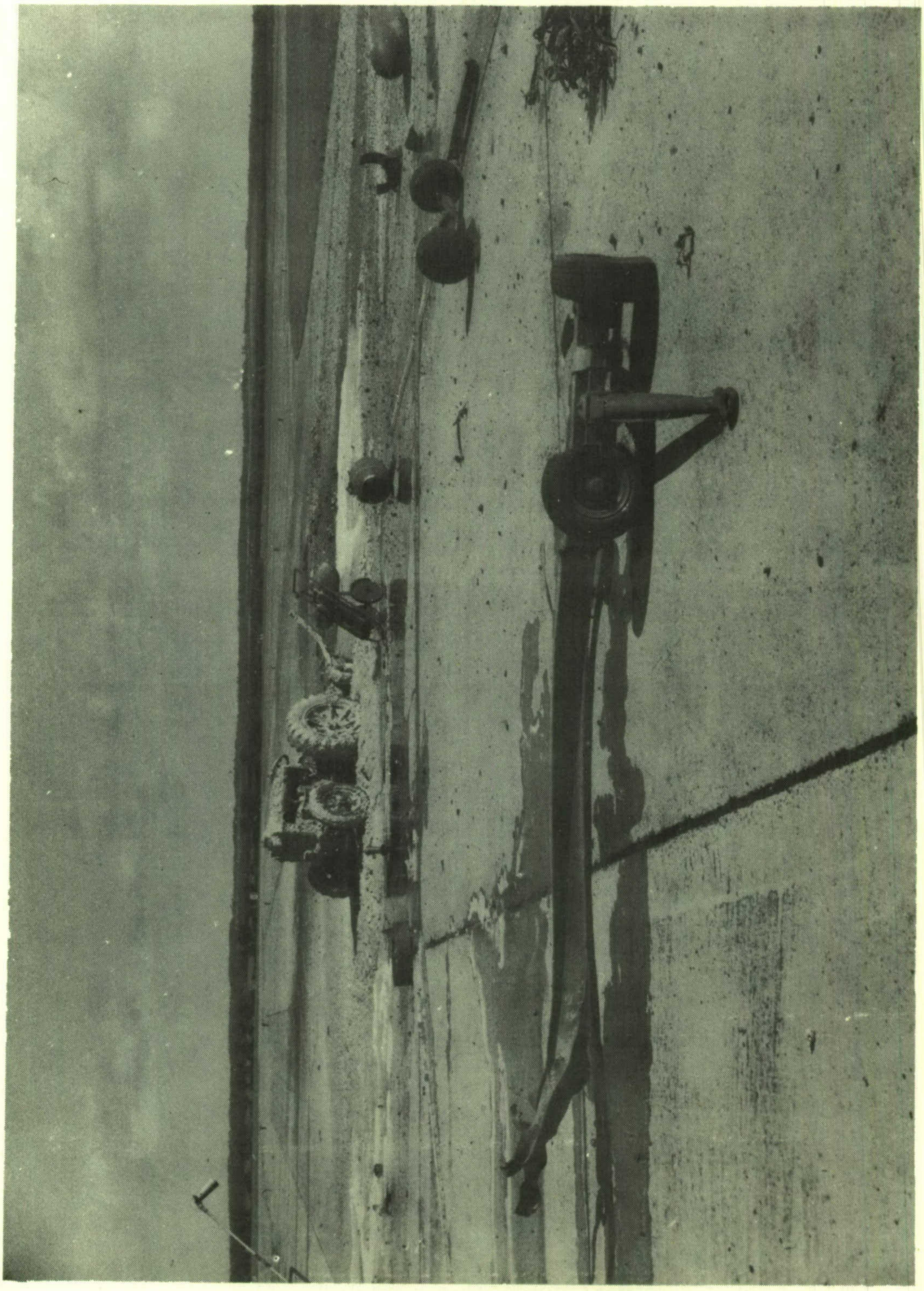


3. Fragments of bomb recovered after the explosion at Marham

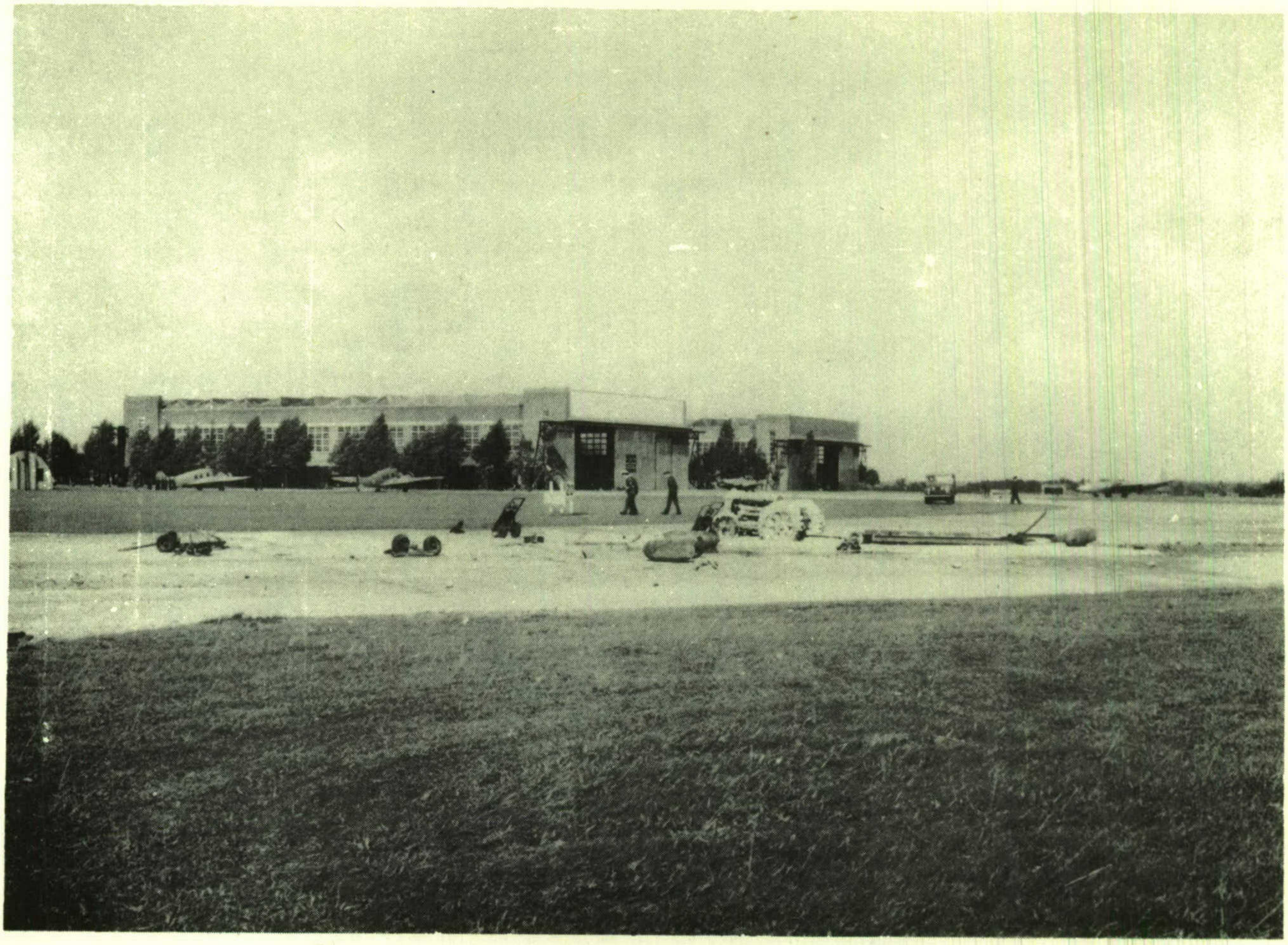
4. The crater from the explosion at Marham

5. The crater from the explosion at Marham showing damaged bombs

SECRET

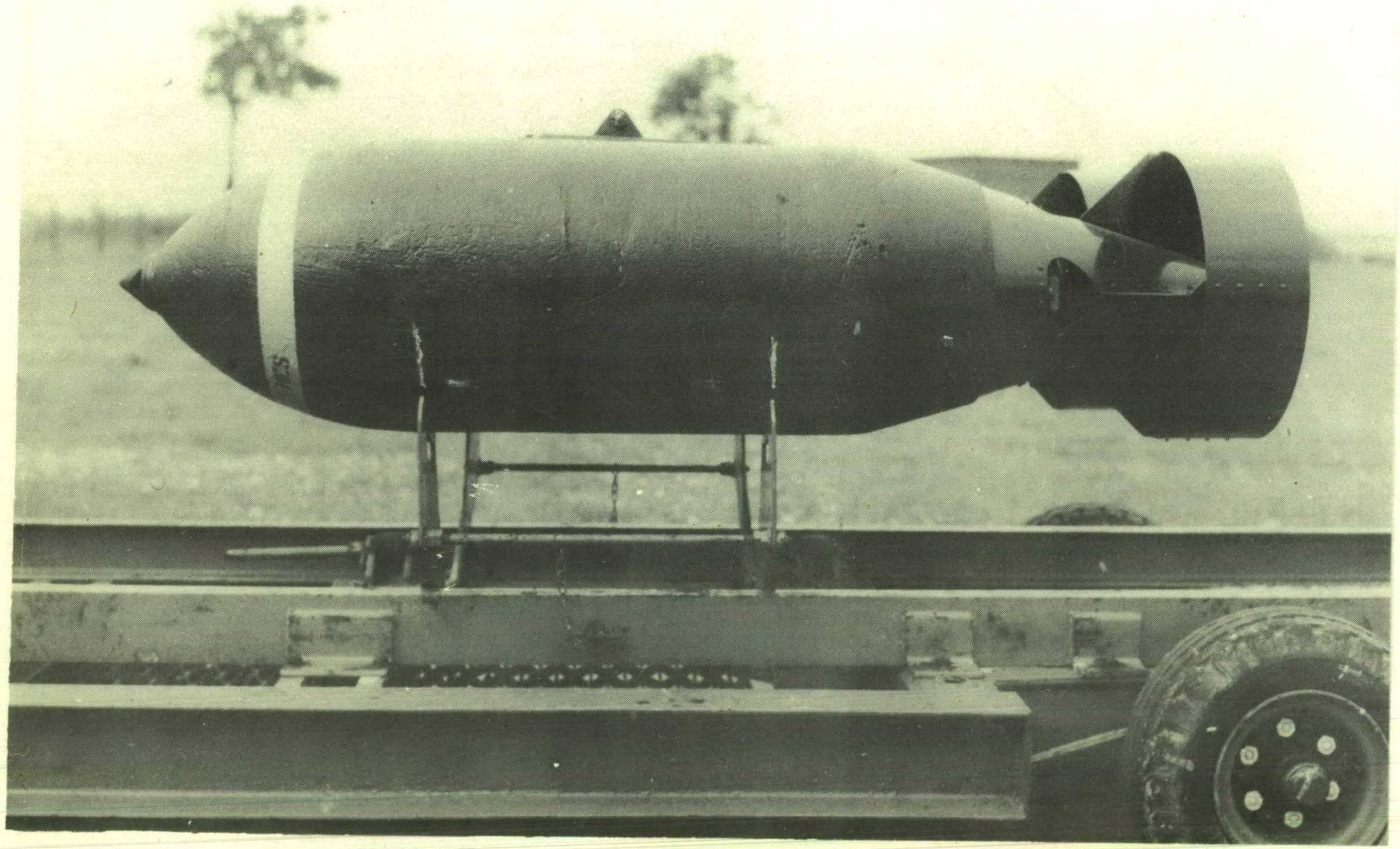


6. The rear bomb trolley after the explosion at Marham

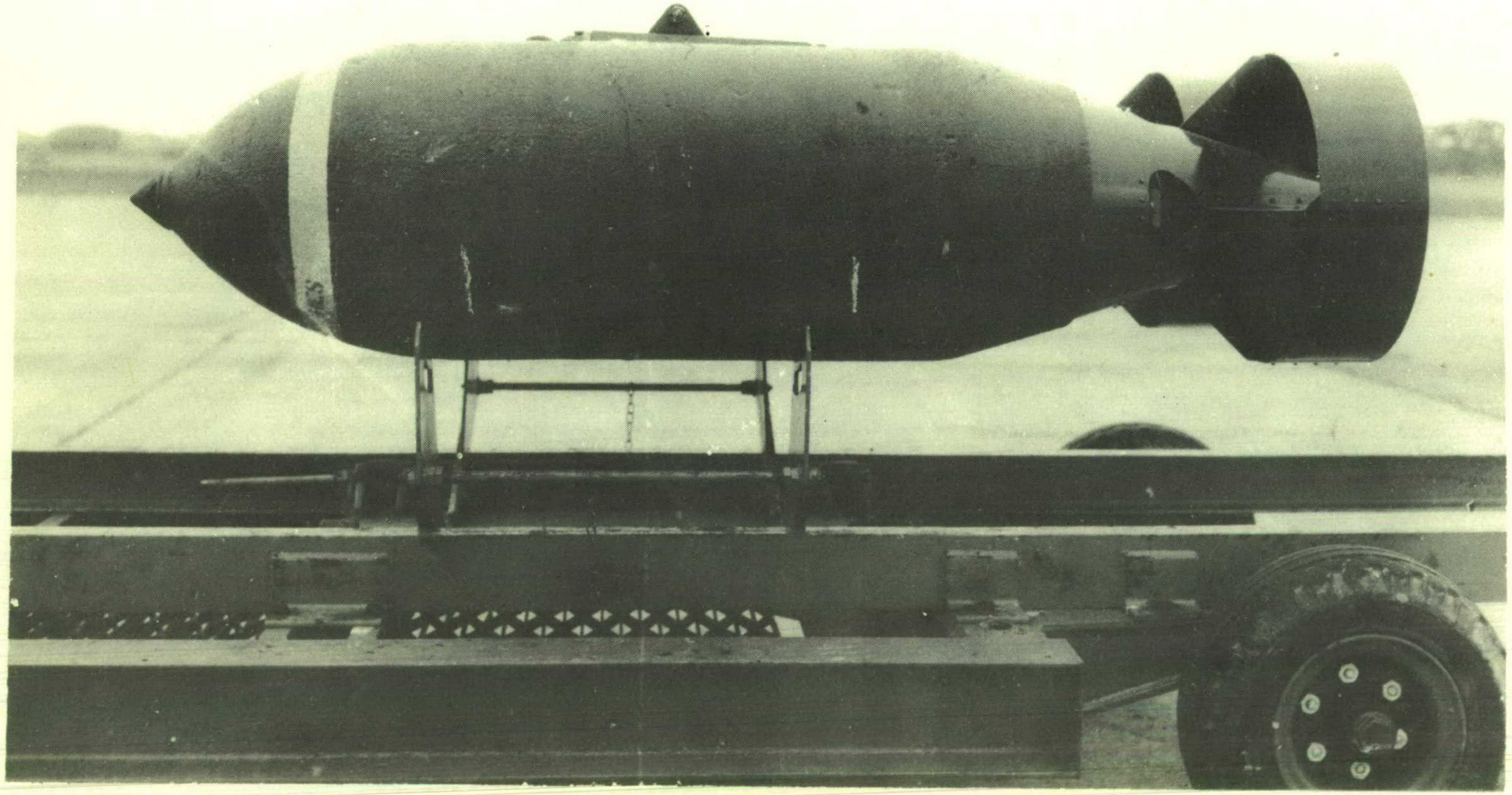


7. General view after the explosion at Marham

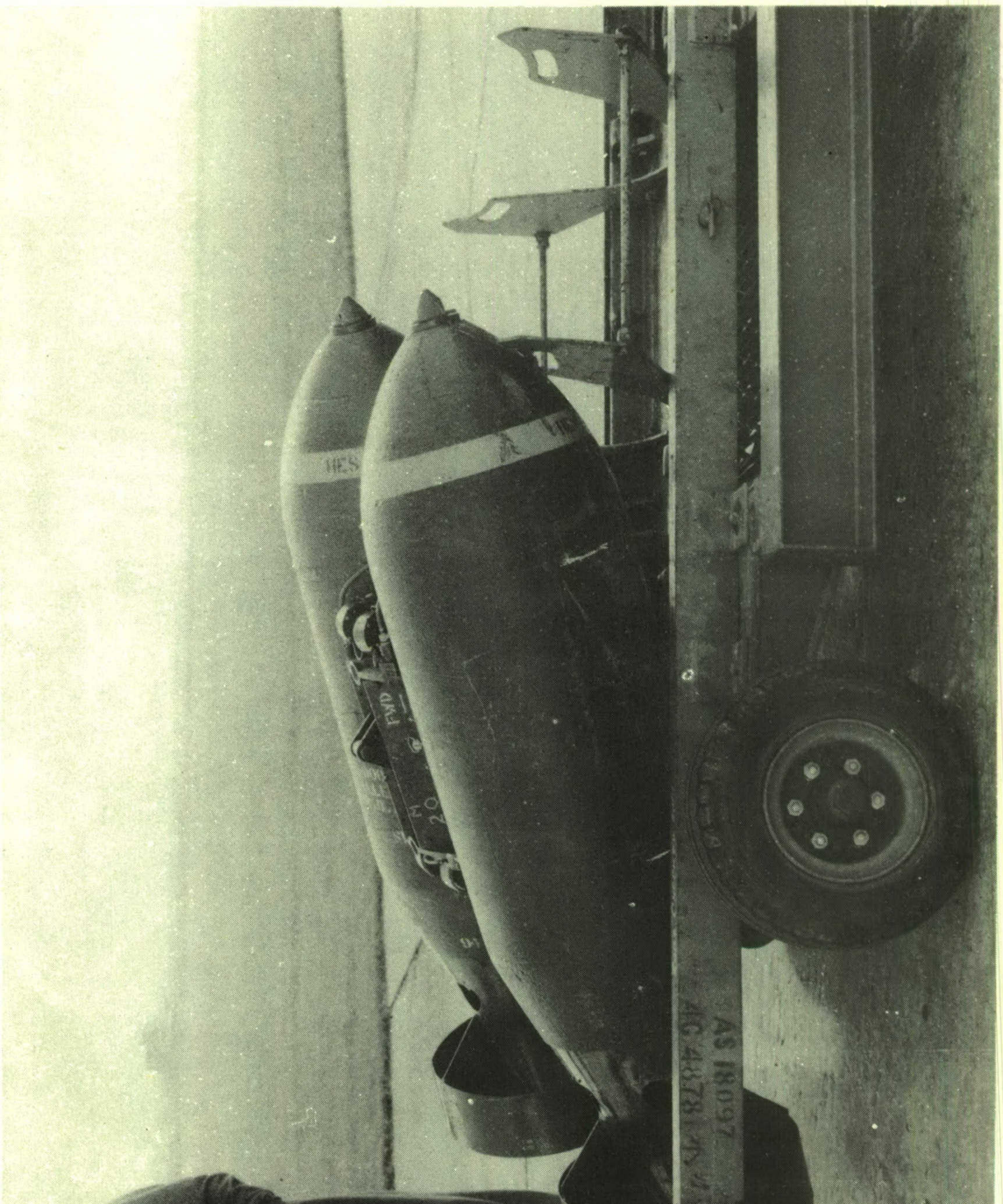
8. General view after the explosion at Marham



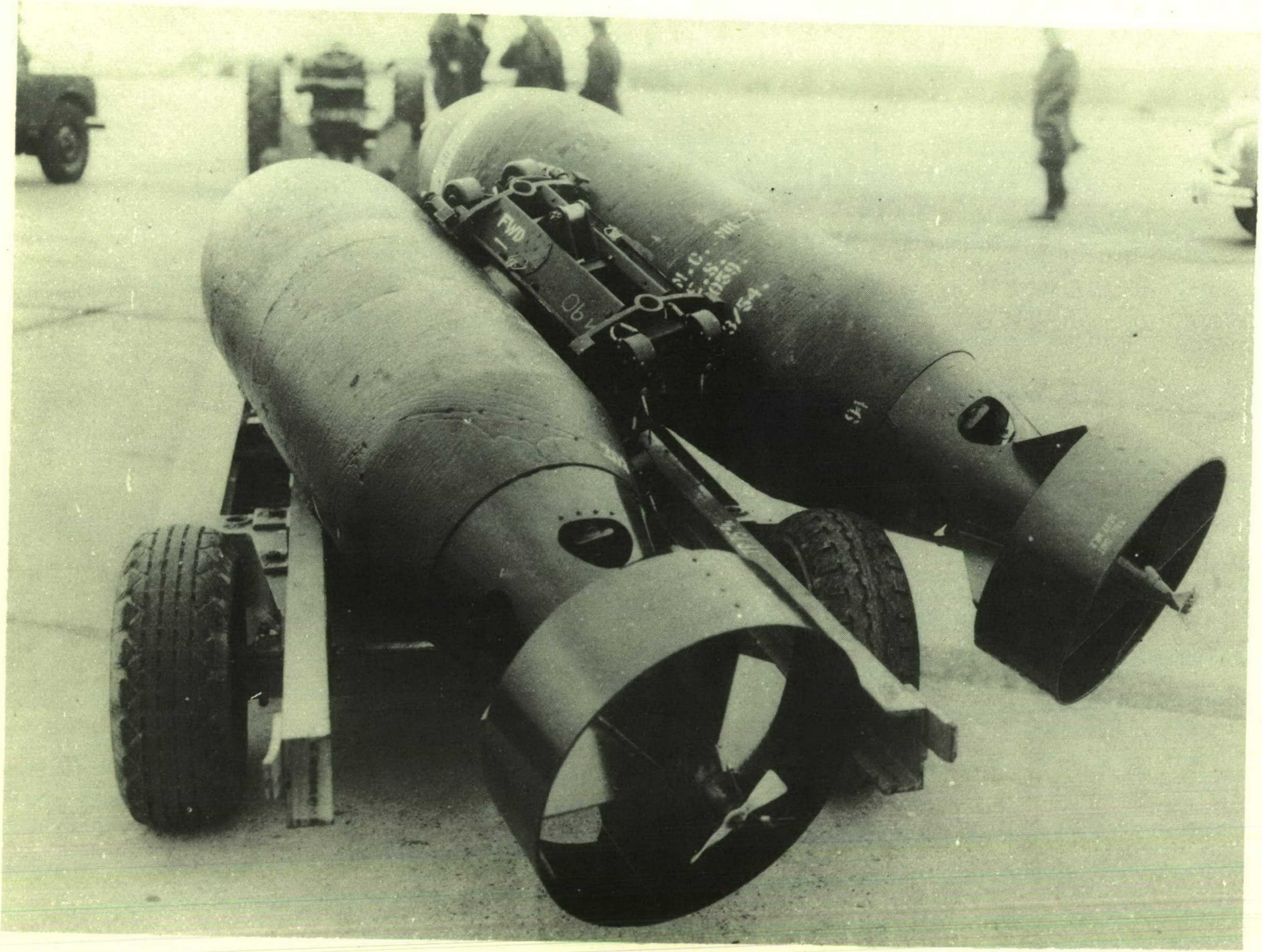
9. Bombs in normal position on cradle of trolley



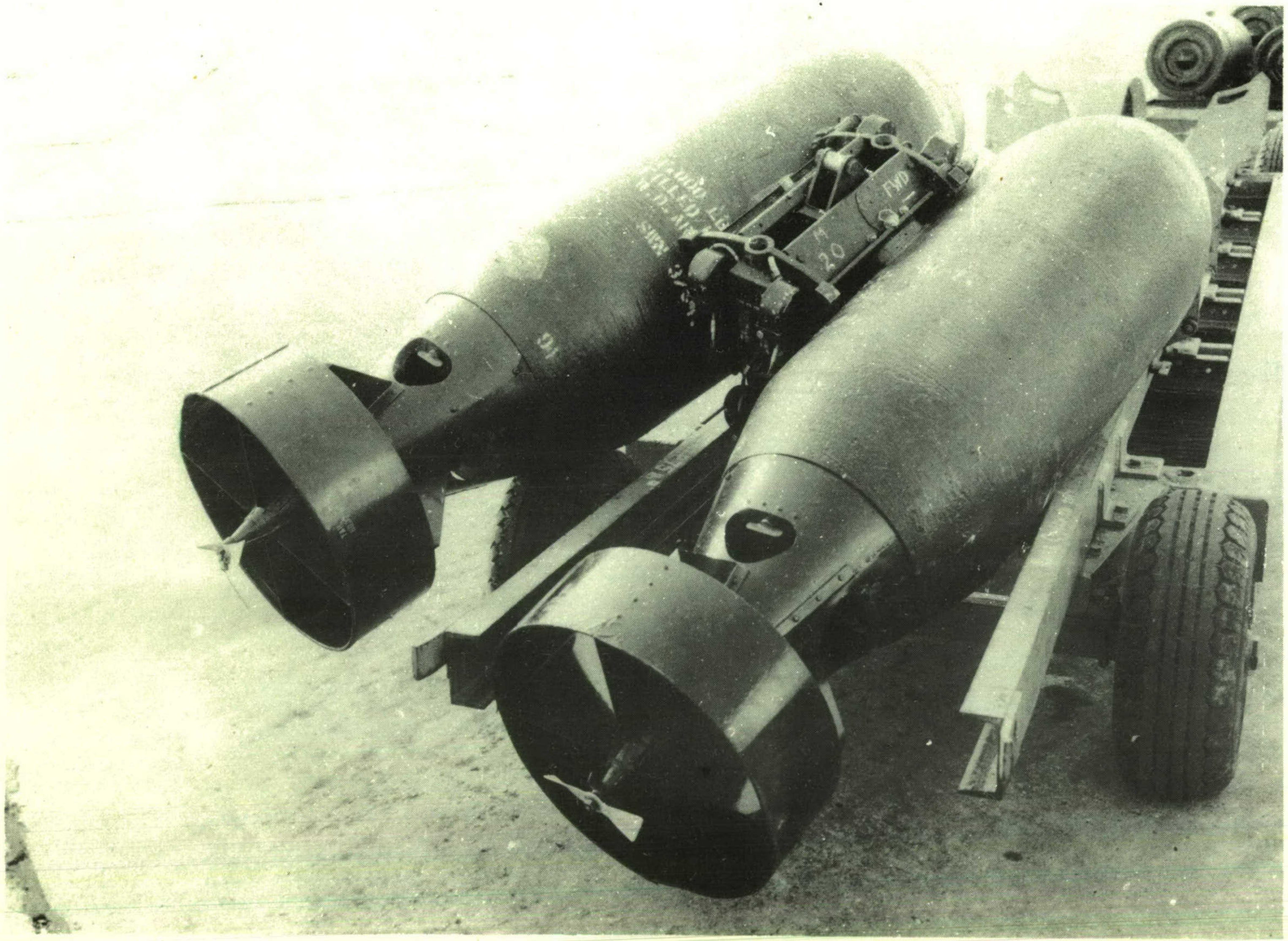
10. Bombs on cradle of trolley showing beginning of backward movement



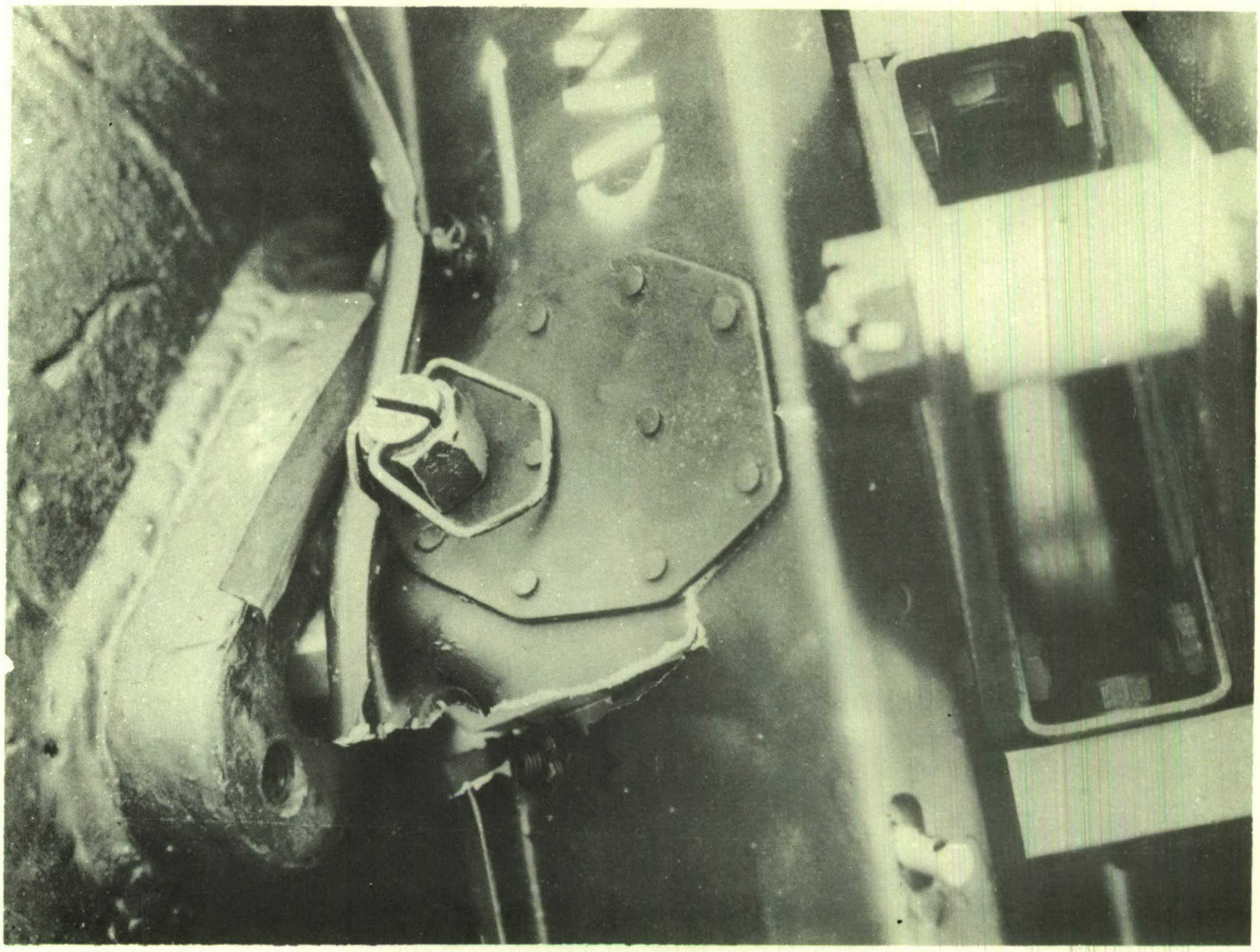
11. Bombs after falling off cradle of trolley



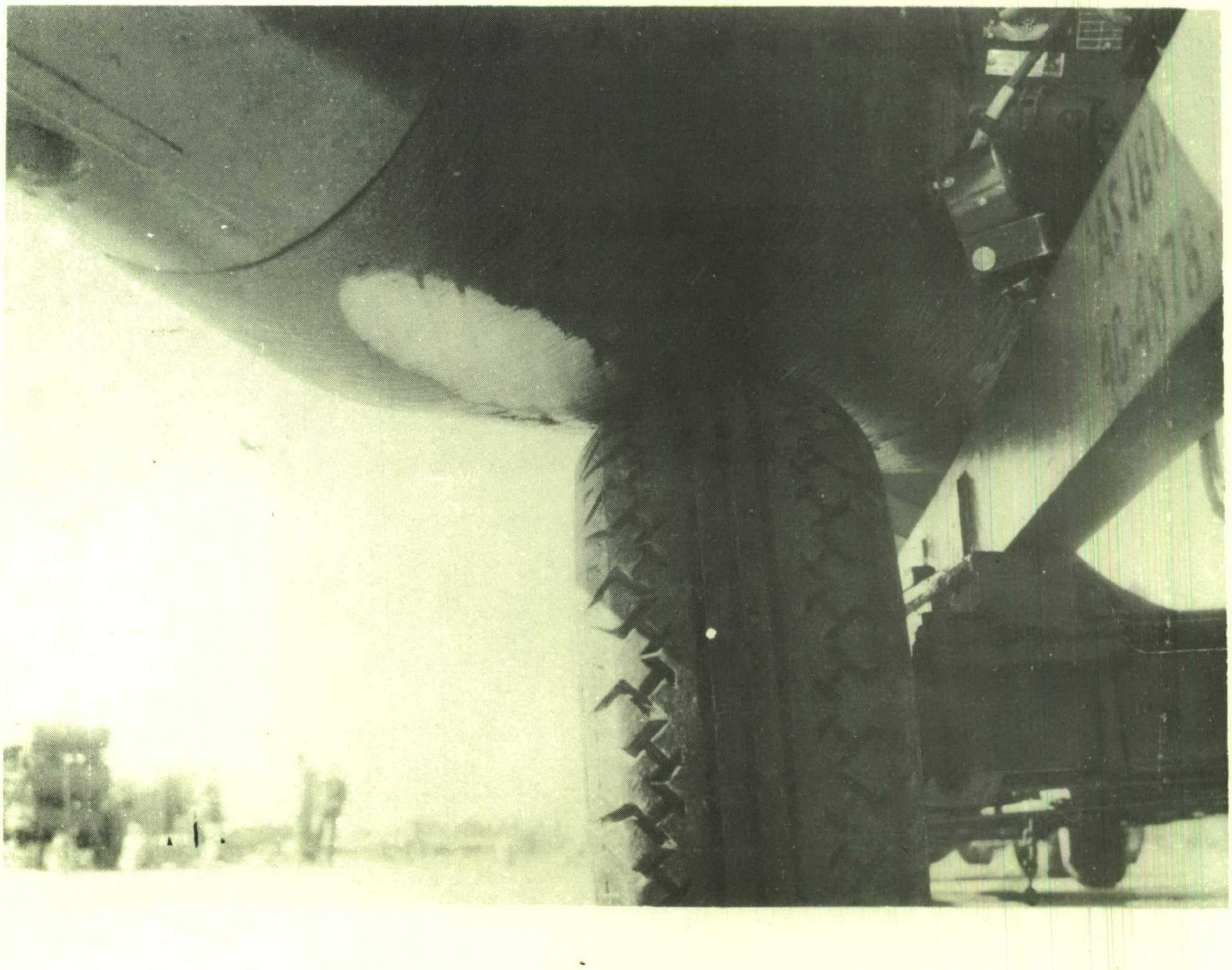
12. Bombs displaced into an unstable position



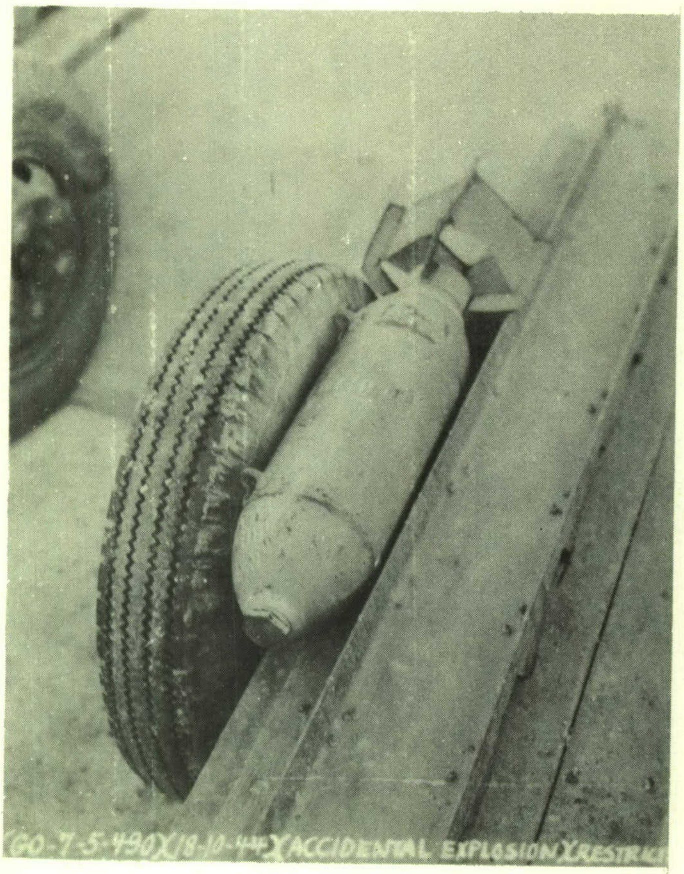
13. Bombs displaced into stable position. Port trolley tyre rubbing on bomb

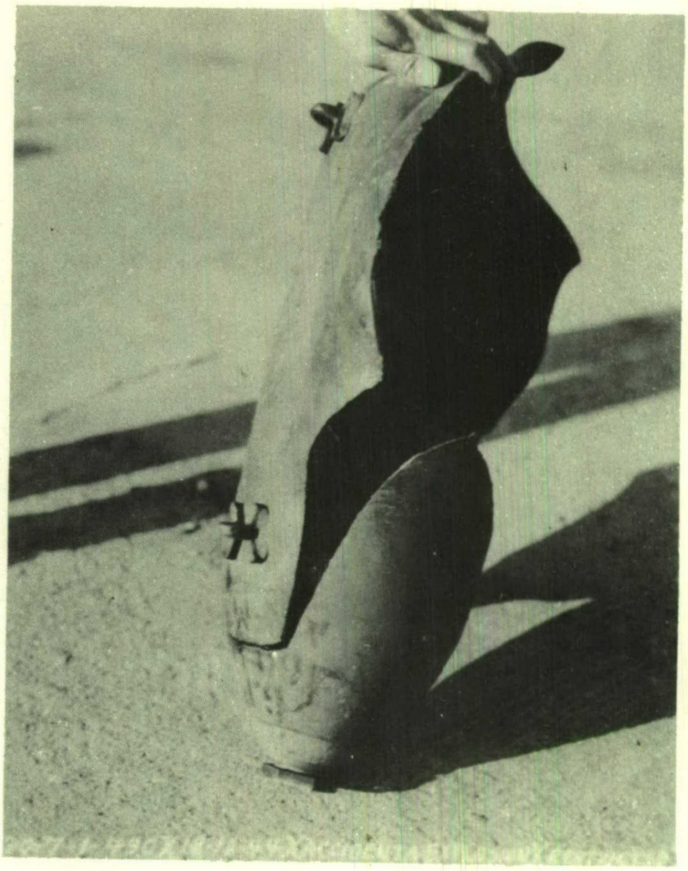


14. Broken carrier



15. View after short run showing paint worn off bomb by tyre



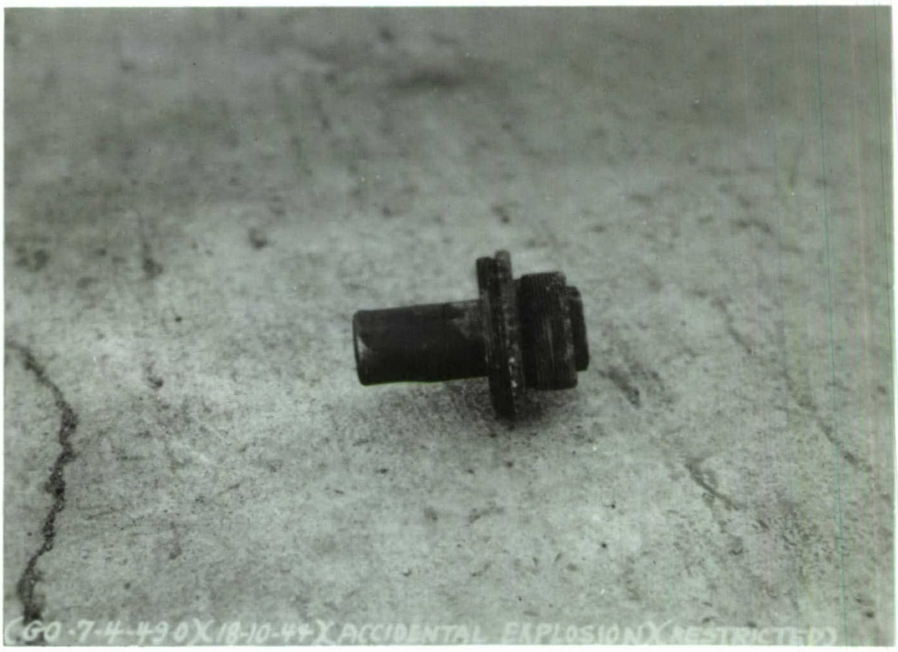


16. Reconstruction of explosion with American bomb

17. Result of explosion with American bomb

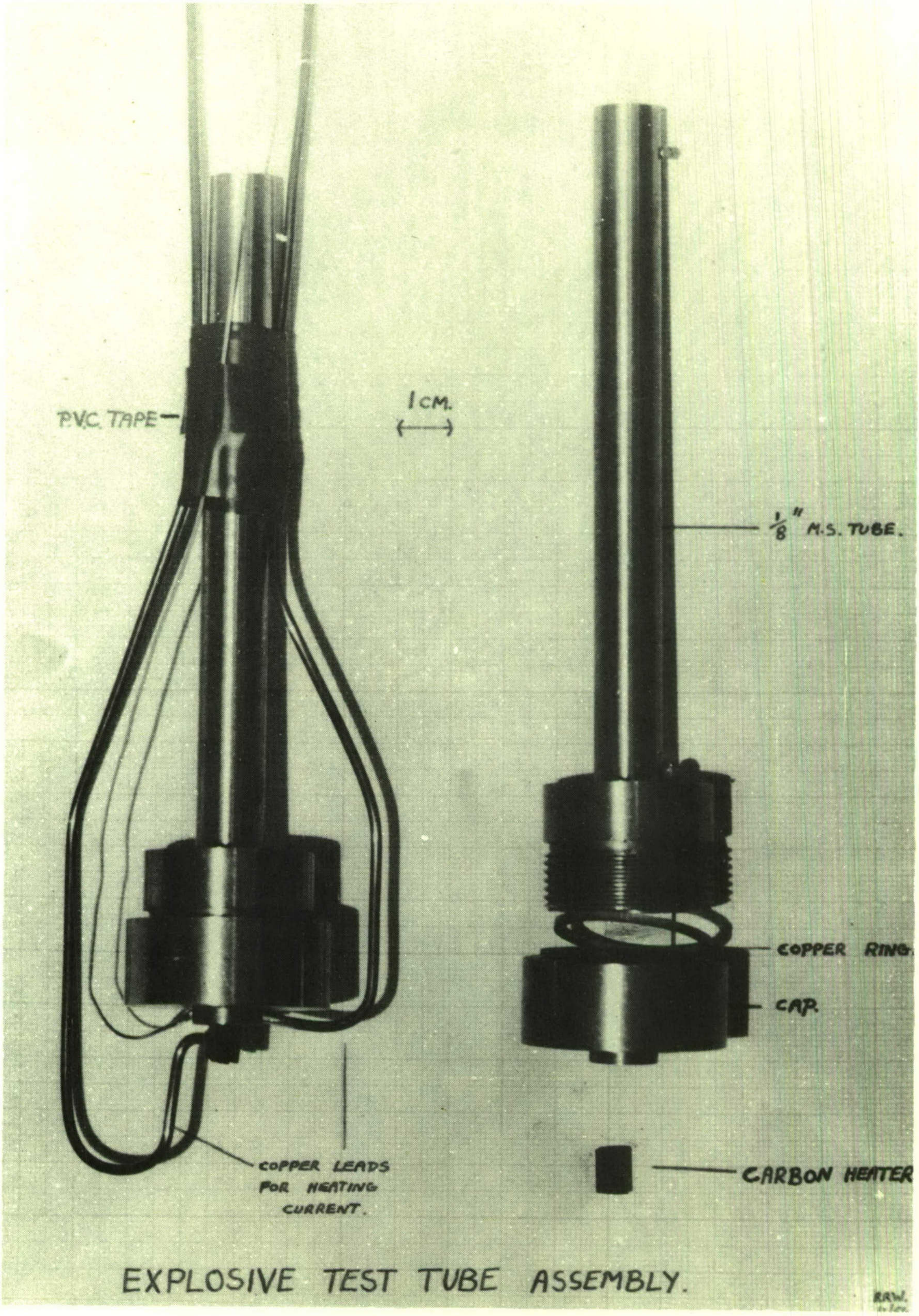
18. Result of explosion with American bomb

19. Inner tube of trailer tyre after explosion with American bomb

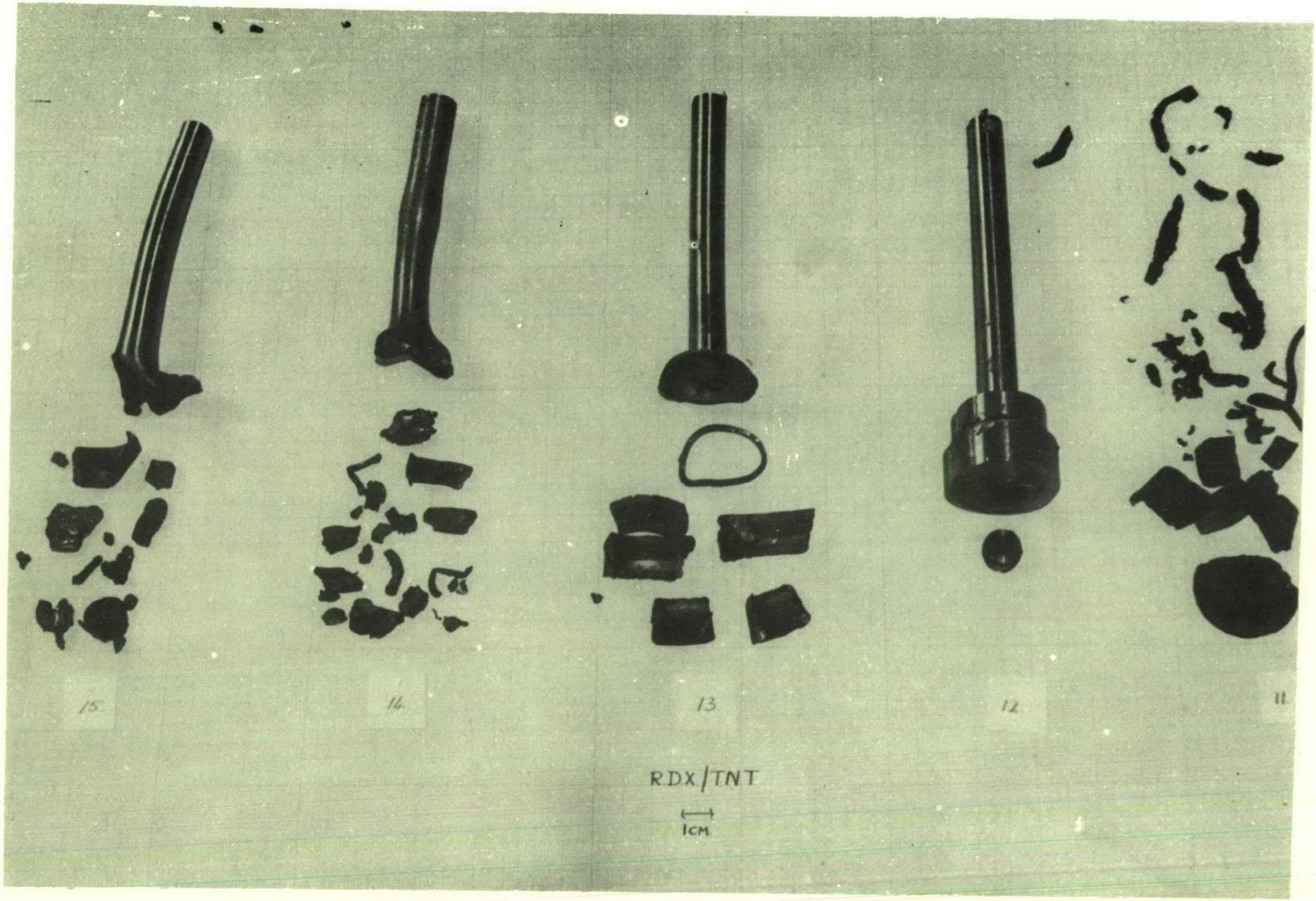


20. Exploder assembly after explosion of American bomb

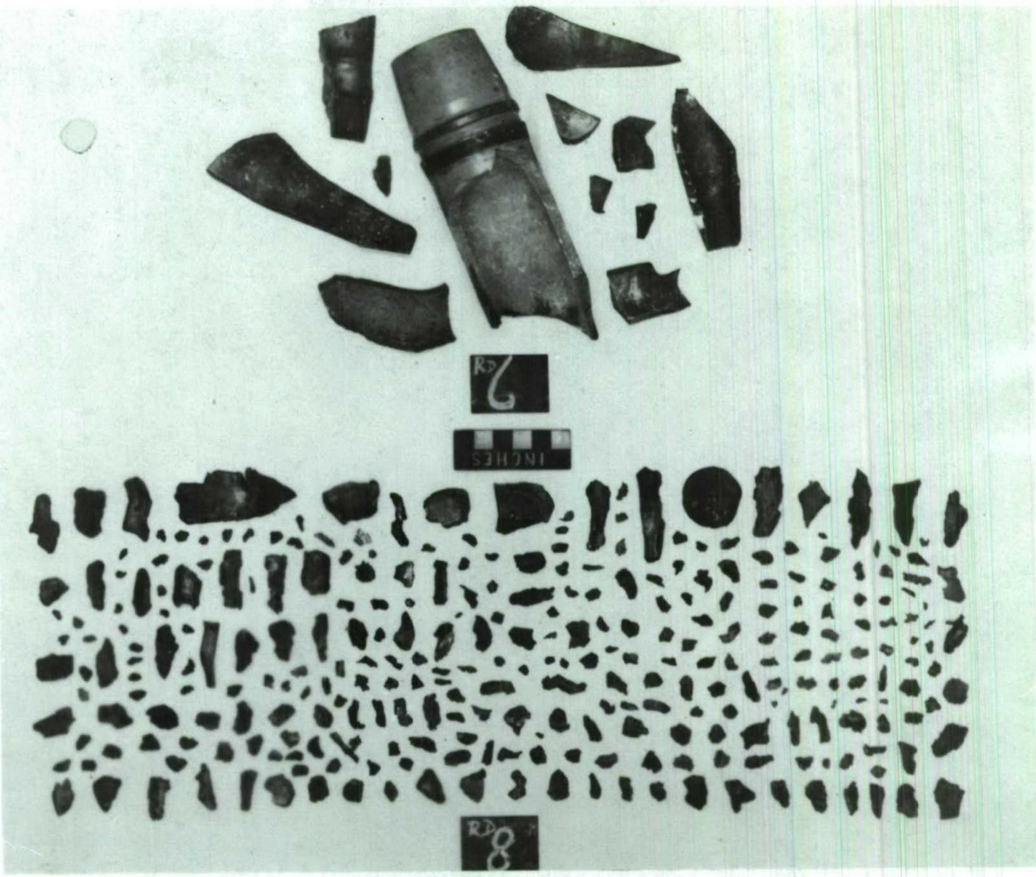
21. Filling from exploded American bomb



22. Tubes used for small scale heating trials of RDX/TNT

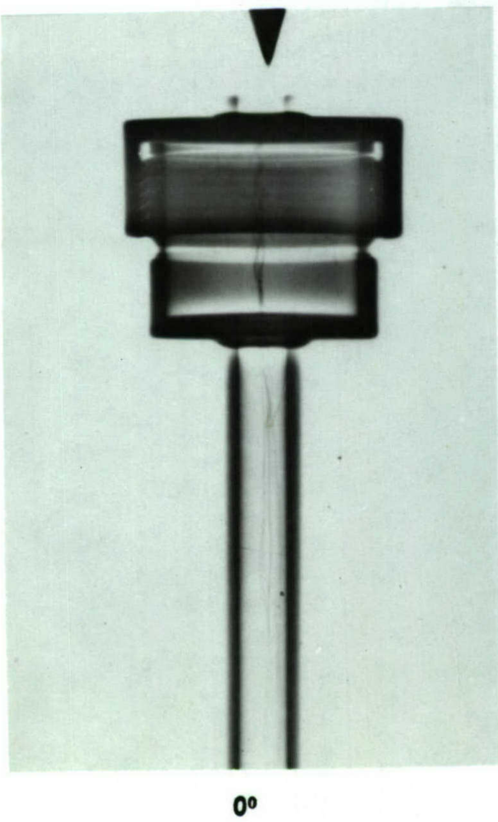


23. Fragments from small scale heating trials of RDX/TNT

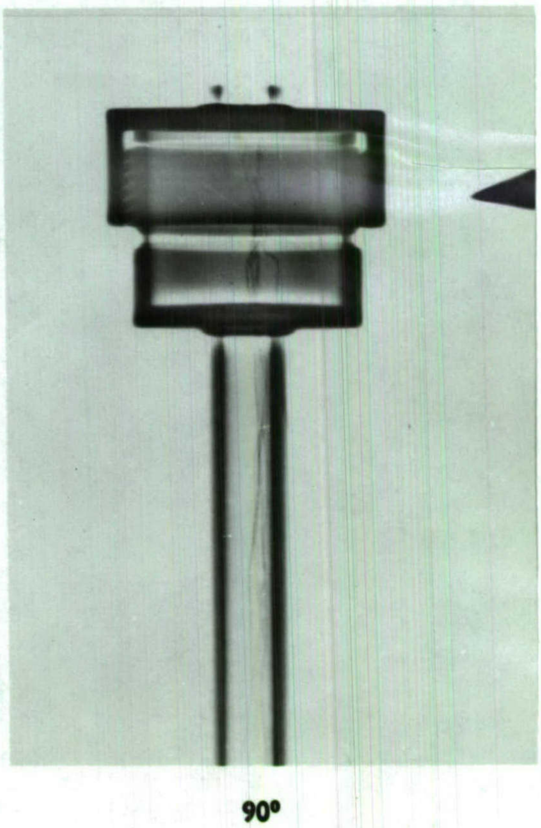


24. Fragments from 5.5 in. shell heating trials

No. 1.



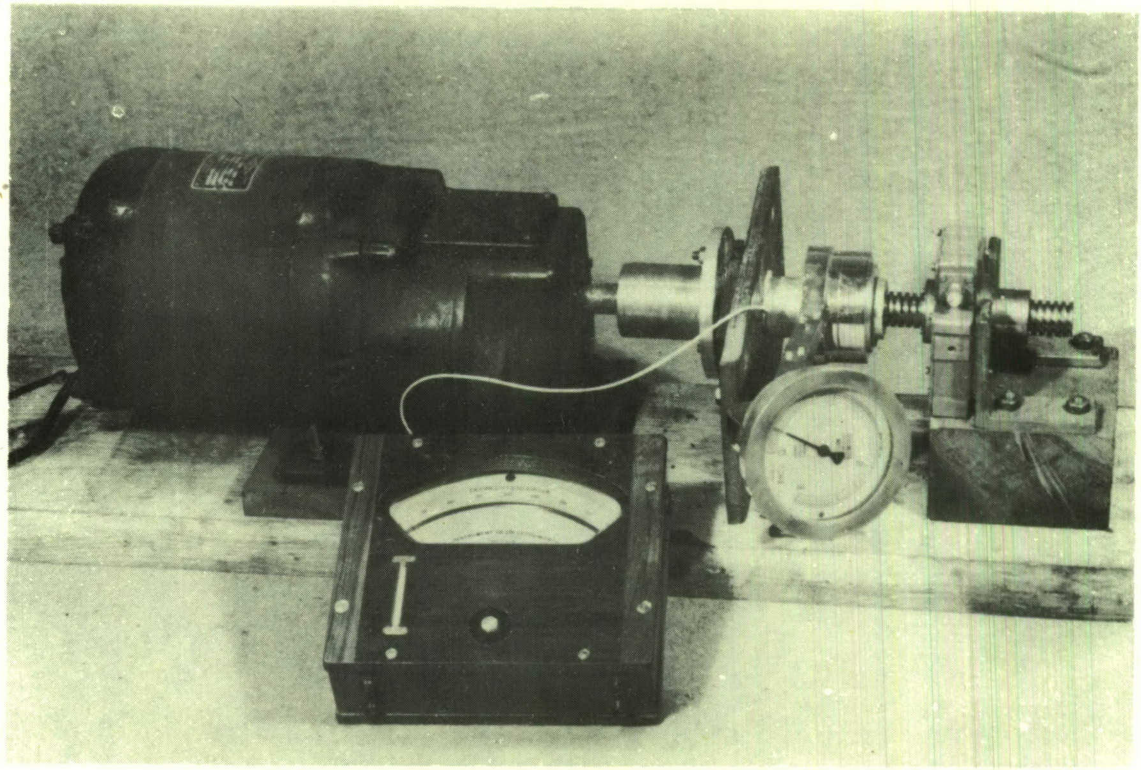
0°



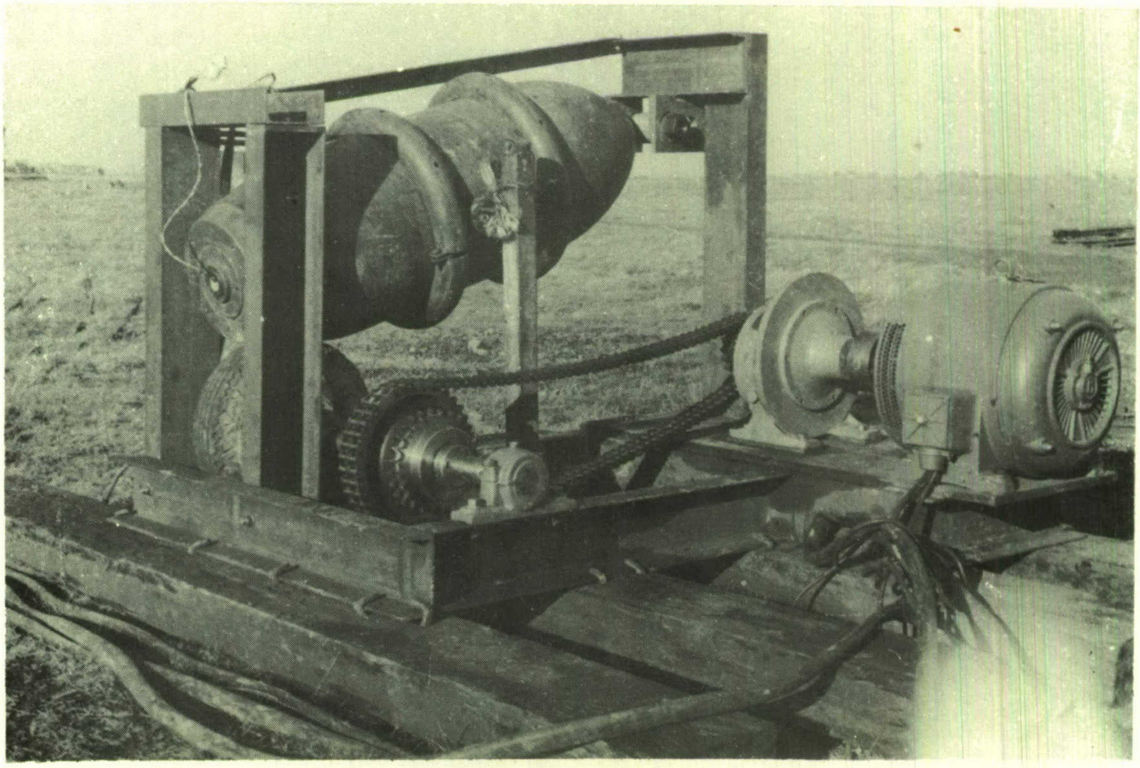
90°

25. X-ray photograph showing thermocouple in small scale heating trials of RDX/TNT

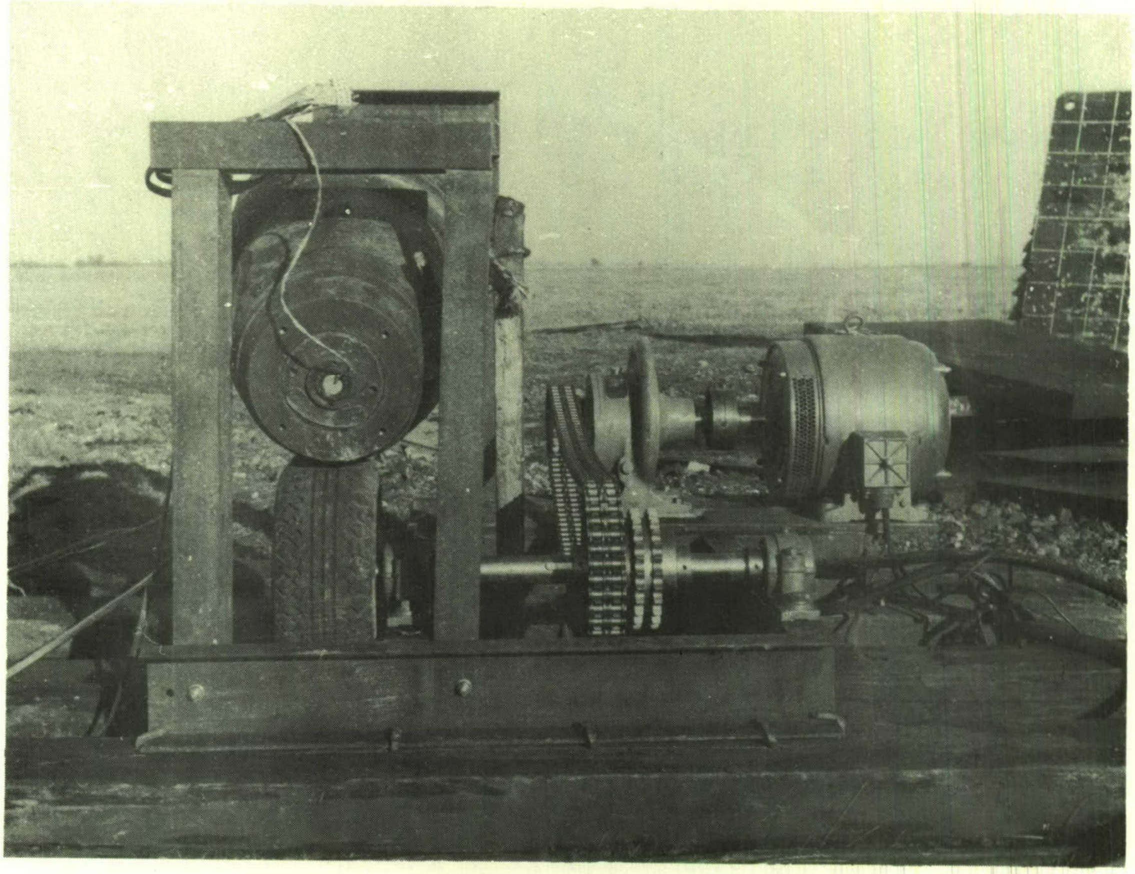
26. X-ray photograph at right angles to Fig. 25



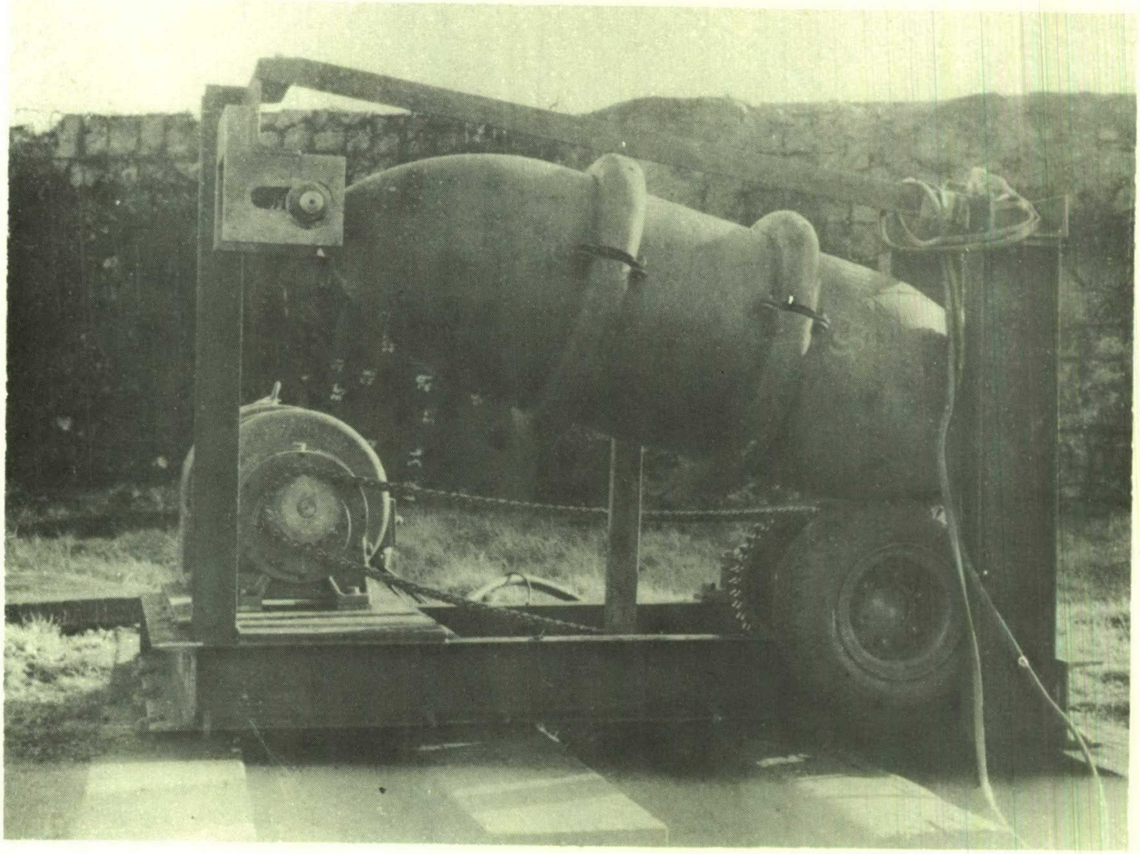
27. Laboratory apparatus for determining frictional heating effects of rubber on steel



28. Full scale test at Shoeburyness



29. Full scale test at Shoeburyness



30. Full scale test at Shoeburyness

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31. Crater from detonation of 1000 lb. bomb at Shoeburyness

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32. Fragments of apparatus recovered from crater after detonation of 1000 lb. bomb at Shoeburyness

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Record Summary: WO 195/13521
Title: Investigation of Accidental Explosion of 1000 LB. Bomb at R.A.F. Station, Marham
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